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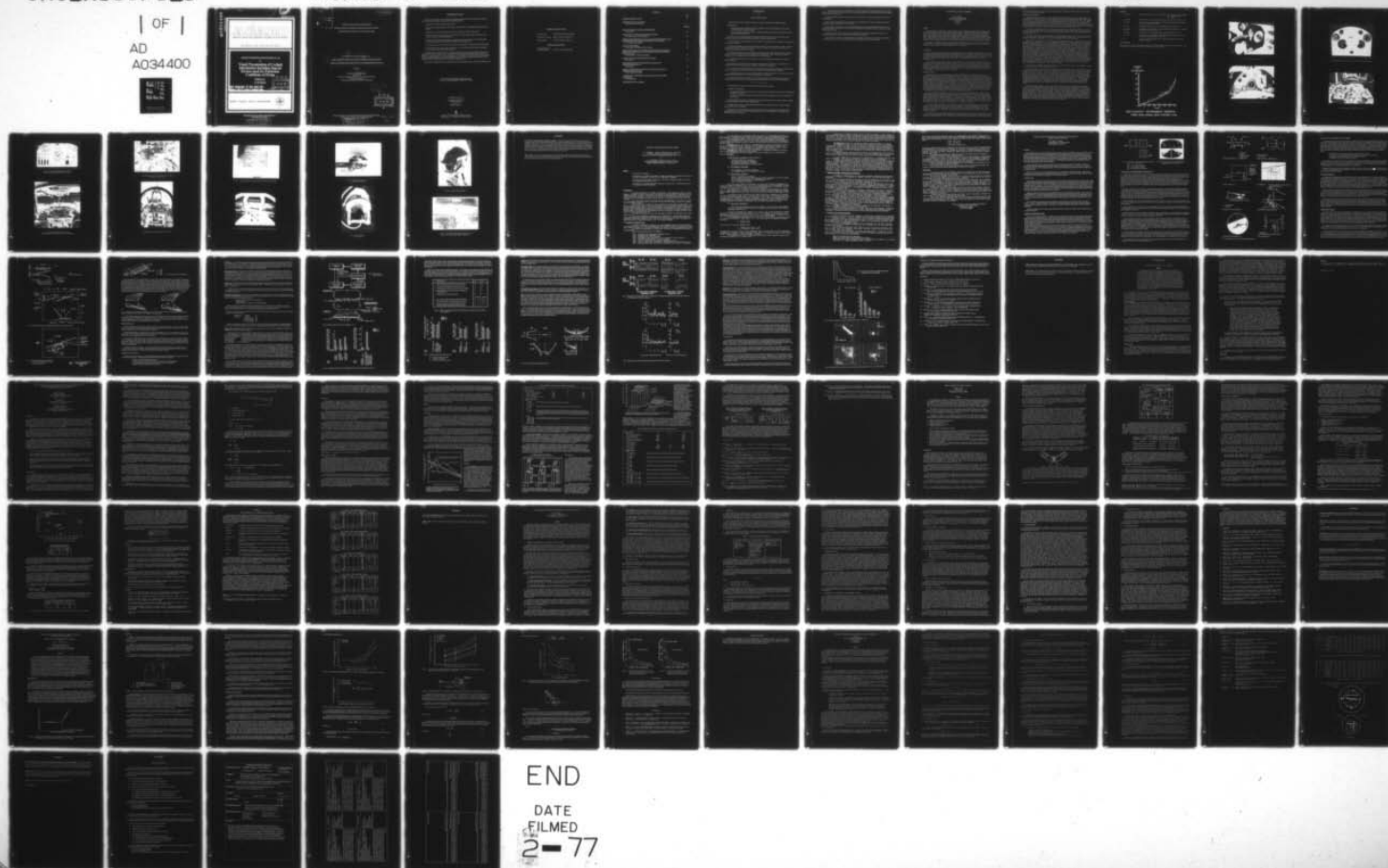
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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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on

Visual Presentation of Cockpit Information Including Special Devices used for Particular Conditions of Flying

Edited by
G. Perdriel

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6
**VISUAL PRESENTATION OF COCKPIT INFORMATION INCLUDING
 SPECIAL DEVICES USED FOR PARTICULAR CONDITIONS OF FLYING**

Edited by
 12
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INTRODUCTION

par

Médecin Général G. Perdriel

L'information visuelle est essentielle pour assurer la sécurité et l'efficacité de la navigation aérienne.

Elle dépend de:

- la qualité des fonctions visuelles du navigant, appréciée lors des examens d'aptitude et des visites de contrôle pratiquées à intervalles réguliers.
- du choix des aides visuelles personnelles et des dispositifs proposés pour la protection oculaire contre les agressions lumineuses excessives.

Mais elle est aussi liée à la présentation des informations disposées dans le cockpit et fournies par certains instruments imaginés pour pallier les difficultés inhérentes à certaines conditions de vol.

Il en est ainsi dans le vol à grande vitesse et à basse altitude où le pilote doit pouvoir conjuguer la sécurité du vol et le succès de sa mission.

Il lui faut alors disposer à tout moment d'informations précises concernant son altitude, sa vitesse, les repères essentiels qui jalonnent son itinéraire, le nombre et la nature des obstacles à son évolution, et parfois aussi, la reconnaissance certaine de l'objectif de sa mission.

Les instruments classiques sont alors insuffisants pour répondre à ces multiples impératifs et des informations exactes ne peuvent être fournies que par des procédés souvent sophistiqués comme l'affichage automatique et synoptique des divers renseignements souvent présentés sur écran cathodique.

Les conditions d'ambiance lumineuse du cockpit doivent aussi être parfaitement adaptées aux opérations diurnes et nocturnes.

Enfin, dans les phases ultimes d'une interception, la visualisation des données pour le contrôle du tir et la conduite de l'avion doivent être parfaitement conjuguées, parfois même synchronisées.

Tous ces procédés ne peuvent être utiles que si les informations qu'ils présentent sont faciles à appréhender par le pilote. Il importe donc de rechercher leurs limites théoriques, mais surtout pratiques, d'efficacité.

Les communications qui vont nous être présentées répondent à cette préoccupation et les conclusions qui seront exprimées doivent nous permettre une meilleure connaissance de ces problèmes.

Pour assurer plus d'efficacité à nos travaux, je vous propose de réserver à la table ronde qui doit clore cette session les questions qui devront être posées par écrit sur le formulaire que vous trouverez à votre disposition.

Visual information is essential for the safety and efficiency of aerial navigation.

It depends on the following:

- the standard of the airman's visual function, as assessed during the initial fitness examination and subsequent periodic re-examinations;
- the choice of personal visual aids and of the proposed devices for protecting the eyes from the effects of excessive light.

Visual information is also related to the display in the cockpit of data provided by certain instruments designed to overcome difficulties inherent in certain flight conditions.

This applies in the case of low altitude high speed flight, when the pilot must be able to ensure both flight safety and the success of his mission.

He must then have instantaneously available precise information about his height, speed, principal reference points along his route, number and nature of any obstacles in the way of his manoeuvres, and sometimes also, definite identification of the target.

Conventional instruments are inadequate in such cases for meeting these multiple requirements and accurate data can be provided only by methods which are often quite sophisticated, such as the automatic and synoptic display of data, often on a CRT screen.

The ambient lighting conditions in the cockpit must also be such as to be perfectly suitable for both day and night operations.

Finally, in the concluding stages of an interception, the data displays for fire control and flight control have to be perfectly matched, and sometimes even synchronised.

However, all these methods are of no avail if the data presented are not easily understood by the pilot. It is important therefore to ascertain not only the theoretical limitations of such methods, but also, and most particularly, their practical efficiency.

The papers to be read at this Conference all deal with this matter which is of paramount concern, and the conclusions expressed are aimed at increasing our knowledge of such problems.

In the interests of efficiency, I would suggest that any questions you may have, which must be put in writing on the form which you can obtain, should be left until the Discussion which is to close this Session.

THE DEVELOPMENT OF AIRCRAFT INSTRUMENTS

by

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SUMMARY

Aeroplanes have developed more or less steadily, since the beginning of the century as man's knowledge of aerodynamics and aircraft structures has increased. Cockpit instruments have also progressed but often in an almost cyclical manner with instrument display format choice depending, apparently, on current fashion rather than on good human factors reasoning. The effects of the cockpit environment upon display design have often been ignored, though some recent advances in display format promise some hope of improvement in future aircraft. Increasing use of cathode ray tube head-down and head-up displays should allow the cockpit designer far more flexibility than has been possible before, but care must be taken to ensure that their advantages are not negated by trying to cram too much information on to them.

This paper is intended to give a brief history of the development of aircraft cockpit instrument layouts and to list some of the short-comings of current instrument displays. An indication of probable trends for future aircraft information presentations is also given.

INTRODUCTION

Some of the very early aircraft had no instruments at all, but compasses, air speed indicators and altimeters soon made their appearance and became standard items in an aircraft cockpit^{1, 2, 3, 4}. To these basic instruments there have been steadily added instruments for engine, fuel, radios, weapons etc. This has produced an almost exponential rise in the number of cockpit instruments (See Fig 1) and a single seat cockpit of a modern strike aircraft might contain over 300 instruments, indicators, controls and switches^{5, 6, 7}.

An aircraft in service today may have a useful working life of over 20 years, during which time its operational role may change quite radically. This will almost certainly require additional equipment and instruments to be added to the already full cockpit. Very seldom are instruments removed to make way for the new. This all leads to very cluttered cockpits which leave a lot to be desired from the ergonomist's viewpoint. Current developments of both head-up and head-down CRT (cathode ray tube) displays may help to overcome this problem but they could also aggravate it, if the philosophy of presenting only the necessary information at the correct time is not observed.

HISTORICAL TRENDS

Aircraft of the 1914-18 era contained few cockpit instruments, most of which were poor but a few of which were surprisingly good, ergonomically (see Figs 2-5). Features of the poorer instruments were railway line markings, (see Fig 4), over-numbering, numbers outside the scales resulting in smaller graduation separation, gas meter type sub-dials within a dial, dials crowded with graduation marks, excessively thin pointers and shiny brass bezels. (Sadly, some of these features are still to be found in relatively modern aircraft.) Of the better features sometimes to be found, were the clear numbering and graduation marking, (see Fig 6), scales numbered by intervals of one or ten and sub-divided by ten intervals, contrasting white numerals and graduations on a matt-black dial. Both good and bad features have been perpetuated in cycles until quite recently. It is interesting to note that strip instruments have come into aircraft cockpits at frequent intervals throughout aviation history (see Figs 6 and 7). Usually, they have lasted for a few years, have then been rejected and disappeared for perhaps a decade before reappearing again. Some wartime strip instruments in British twin engined bombers look surprisingly similar to the current strip displays which have reappeared in American airliners and helicopters.

The choice of strip displays for an aircraft cockpit would appear to depend upon current fashion rather than on good ergonomic reasons. Strip displays are certainly more difficult to read than conventional circular dial and pointer instruments under the vibration conditions to be found in helicopters. One can always detect the angular position of a pointer on a circular dial no matter how blurred it might appear due to vibration. The linear position of the pointer on a strip instrument is far harder to sense, and usually will have to be very carefully read, since it is more difficult to detect linear positions or movements than angular ones. This is particularly so if vibration is present. Vibration blurred scales and pointers can form nodal images which are difficult to relate to one another.

A frequent argument in favour of strip displays is that if used, for example, in a multi-engined aircraft to show engine speed under normal operating conditions, the vertically mounted strips can be scanned along and any deviation from the norm on one engine can be detected immediately. This form of scanning for faults has of course been used in cockpits for many years with circular dial and pointer instruments, by rotating the instrument in its mounting until the pointers are horizontal for normal operating conditions.

As a leading aircraft instrument manufacturer⁸ states 'Although the vertical tape instrument has some advantages over the circular scale instrument, it sometimes presents a problem when allocating panel space because of its awkward shape as well as presenting an ergonomic problem when used in serried ranks; when

the pilot might not always be able to sort out quickly which of the many vertical lines is the one with which he is immediately concerned'.

CURRENT AND FUTURE TRENDS

Because modern aircraft tend to be very complex pieces of machinery, with many separate systems, all of which need to be monitored, their cockpits contain almost as many instruments as the panel space allows. (See Figs 8 & 9). Often the panel space is inadequate and space saving techniques are used. For example, 2 or 3 pointer instruments are used. These instruments certainly save space, but at the cost of greater reading difficulty and increased errors. The fatal accidents which have been caused by misreading the 3 pointer altimeter are well known examples of the results of poor display design. (A single pointer altimeter combined with a digital readout overcomes most of the problems associated with the 3 pointer instrument giving both height and rate of change of height information in forms readily assimilated.)

Panel space could sometimes be saved by replacing instruments with more simple indicators. Often the pilot or flight engineer needs only to know whether the system is within limits, which can be indicated by warning lights or flags. He does not need to know the precise state of the system which requires to be indicated on the dial.

Even when he does need to know the precise value of the parameter that he is monitoring, he may need to check it only once or twice per flight, eg the brake accumulator pressure gauge. For the rest of the time the instrument is cluttering up the cockpit and possibly acting as a distraction.

Today, by using CRT displays in the cockpit only that information which is currently required need be displayed. With a CRT display the pilot will probably be given the basic flight information of air speed, altitude, attitude, heading etc. He could select other quantities such as checklists to be displayed (see Fig 10), while system malfunctions could be programmed to be presented to him automatically. A separate CRT display could be provided to give navigational information, fuel state etc. The artificial horizon and basic flight information might be combined with a low light television view of the outside world for night operations. Alternatively, the basic flight information may be superimposed on the real world by using a HUD (head-up display). In this instrument, the CRT image is projected onto a screen in front of the pilot and collimated, so that he sees the information 'outside' the cockpit at infinity (see Fig 11). This has the advantage that he can maintain his view of the outside world without having to look 'head-down' to read his speed from the conventional panel mounted air speed indicator. The HUD is particularly useful when, for example, approaching a runway in fog where the pilot needs to keep his eyes skinned. At this time the pilot has little time to see and to recognise the runway and then to decide whether it is safe to attempt a landing. Any time spent looking within the cockpit will reduce his chances of attempting a landing. Consequently, a HUD can be of immense benefit in some marginal situations. Despite its advantages the current HUDs have the serious shortcoming of an inadequate field of view. Only a small part of the outside world can be seen through the HUD 'porthole'. This results in HUD clutter, which would be reduced if a larger field of view could be provided.

The HUD has the additional advantage of producing a collimated image which is less effected by vibration than conventional headdown displays (see Fig 12).

Despite the potential advantages of CRT displays there is a danger that their full value will not be realised. The tendency to try to put too much information on the display is strong and must be countered by good human factors guidance. Since man is effectively a single channel device, albeit one that time-shares, there is little point in trying to present him simultaneously with all the information he needs throughout the entire flight, when he can only process a relatively small amount of it at any one time. This is exactly what is happening with the latest display presentation such as the helmet mounted display. The helmet mounted display could be described as a development of the helmet mounted sight which usually consists of a boresight with a limited amount of additional information added to it. The device is collimated and provides a simple display in front of the operators' eye (see Fig 13). It is designed to improve the man's ability to aim weapons or sensors at potential targets by merely looking in the target's direction; sensors on the helmet feed data to a computer which calculates where the man is looking.

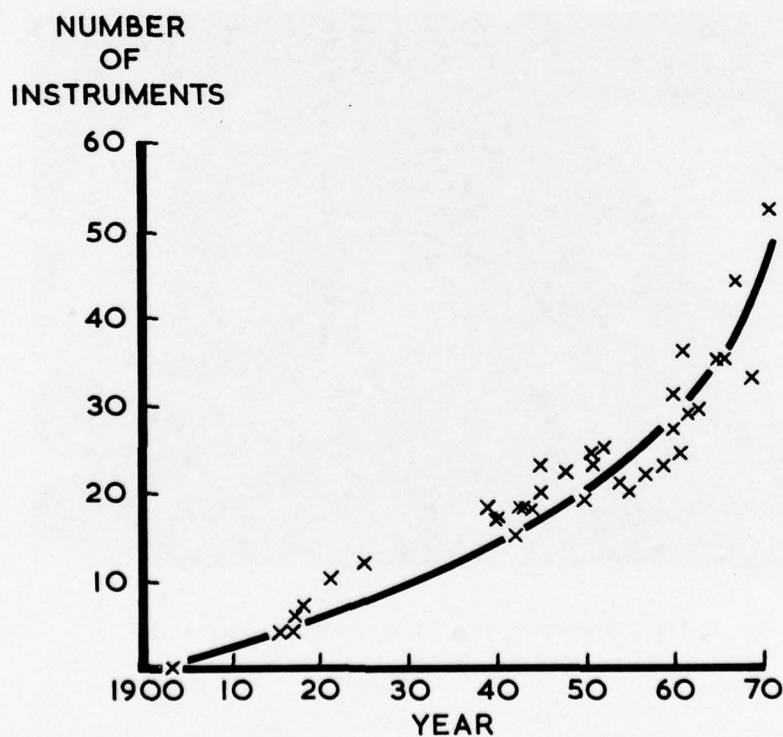
The helmet mounted display is a more complex device which produces an instrument display in front of one eye of the pilot, leaving his other eye free to view the real world (see Fig 14). It has been claimed that by presenting a collimated display directly in front of the eye, information can be displayed over a far greater area than can be done by HUDs or by cockpit instruments, whose area is limited by the need for windscreen and other cockpit equipment. While the helmet mounted display is potentially a most useful device much of the effort, so far, seems to have gone into maximising the amount of information displayed to the man. Few have questioned whether it is the correct information or how much of it he can process. Unless these aspects receive the attention that they clearly desire, the future pilot will be presented with more and more information which will be utilised by him less and less. The cost of his displays will increase and so will his workload but the overall efficiency of the man machine system will decline due to the ergonomic shortcomings of the display interface.

REFERENCES

- 1 L F E Coombs Front Office Evolution 1-6, Air Enthusiast 1972 - February, June, November 1973 - April, October 1974 - August
- 2 R A Chorley Monitoring Aircraft Displays, Smiths Industries Journal No 33 April 1975
- 3 R A Chorley Seventy Years of Flight Instruments Displays, The 3rd HP Folland Memorial Lecture, 19 February 1976 RAeS
- 4 J M Rolfe The fighter cockpit 1910-1963. RAF IAM Report No 222 June 1964
- 5 F/Lt M Shaw
W G A Port A comparison of the number of cockpit displays and controls in six military aircraft, RAE Report TR 82140 1972
- 6 J W Fozard The Harrier. J D North Memorial Lecture, RAeS Journal Sept 1969
- 7 P G Harlow A comparison of the number of cockpit displays and controls in 8 military helicopters, Unpublished RAE Report 1974
- 8 Anon Evolution of the Instrument Panel. Smiths Industries Aviation Review Vols 32, 34, 1976.

ACKNOWLEDGEMENTS

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**FIG.1. COCKPIT INSTRUMENT GROWTH
FIXED WING, SINGLE SEAT FIGHTER TYPE**

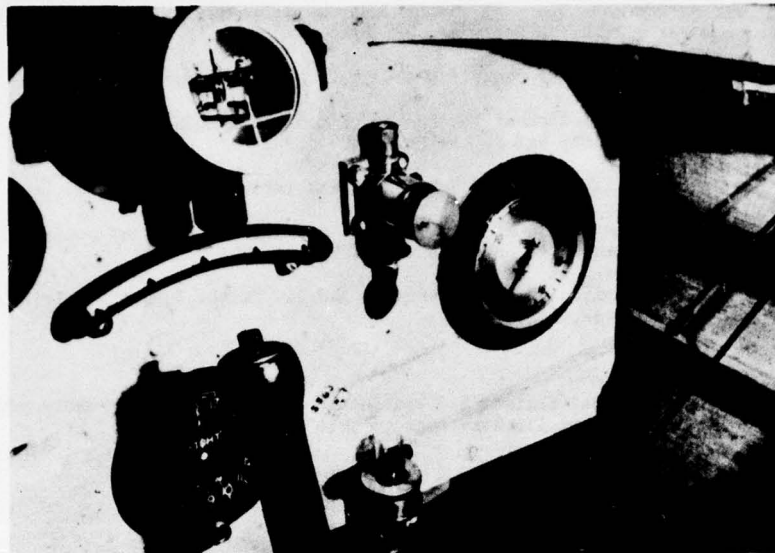


Fig 2 Avro 504 Cockpit, circa 1915

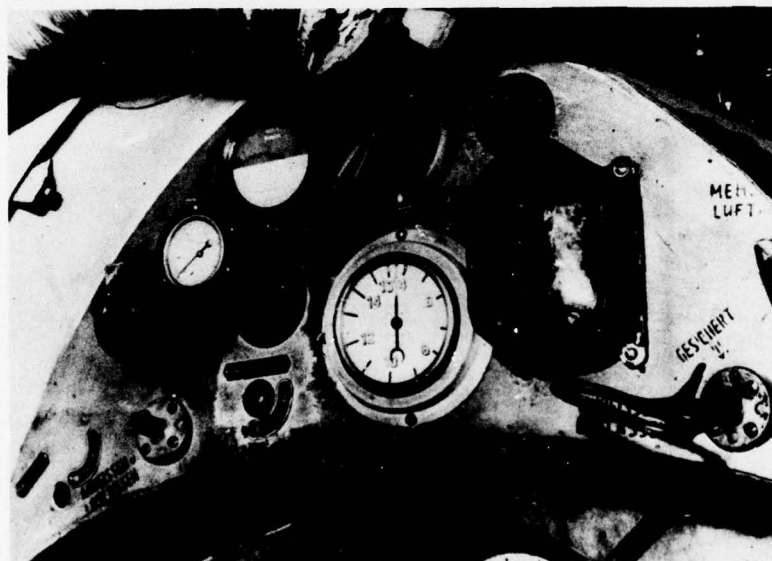


Fig 3 Brandenburg D1 KD instrument panel circa 1917

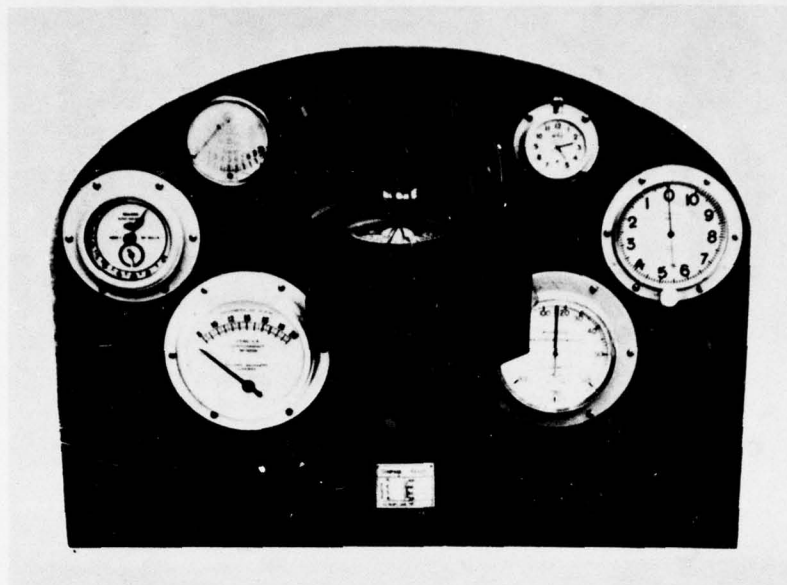


Fig 4 Early instrument panel showing both good and bad features

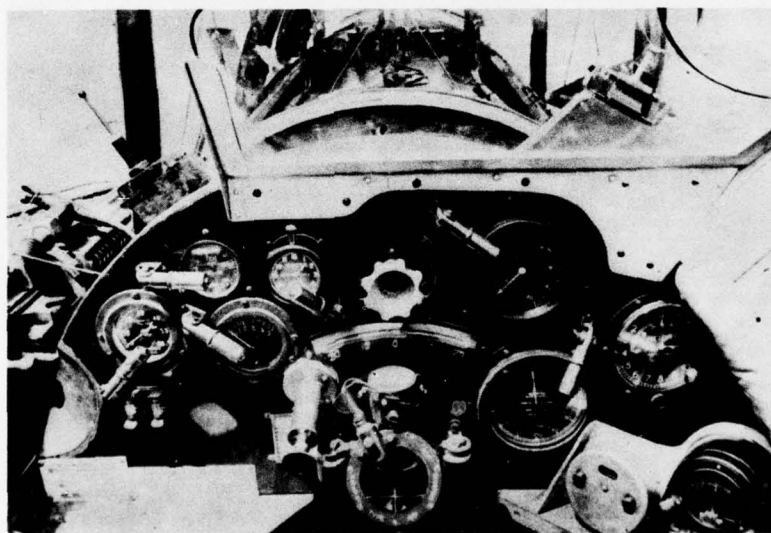


Fig 5 De Havilland 9A cockpit, circa 1918

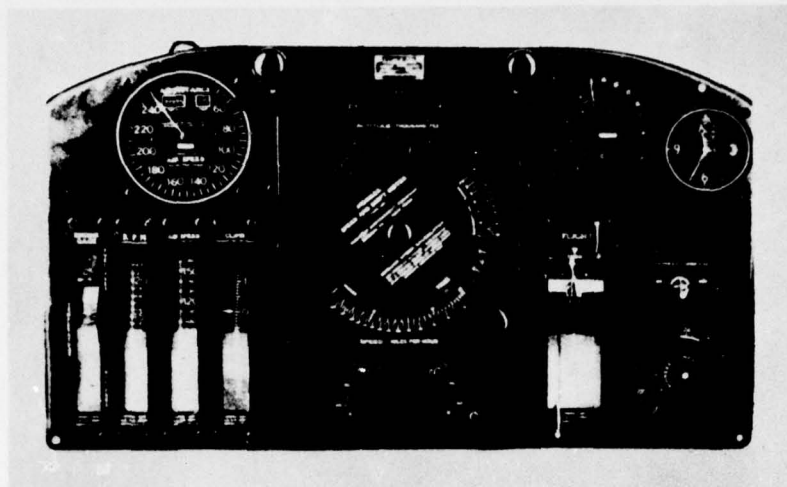


Fig 6 A Pioneer instrument panel of 1925 showing strip displays and well designed ASI

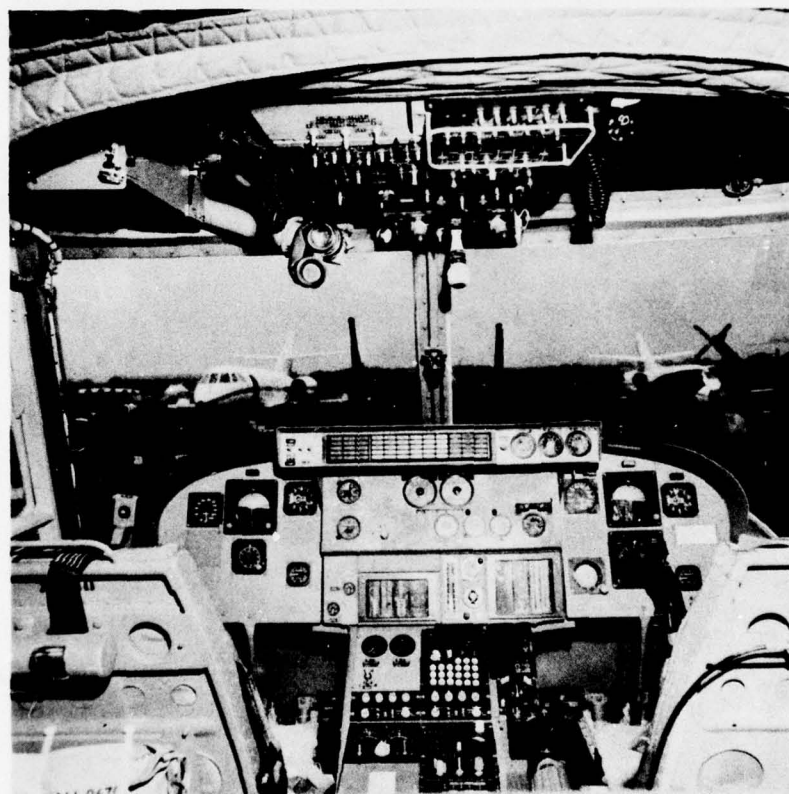


Fig 7 Lynx helicopter cockpit, 1974, showing strip and conventional circular instruments

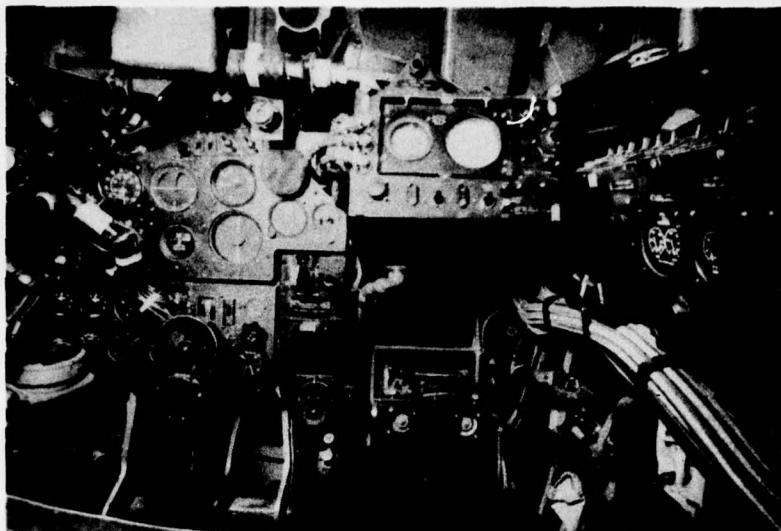


Fig 8 Mosquito NF 38 showing early use of CRTs
in cockpit, circa 1950

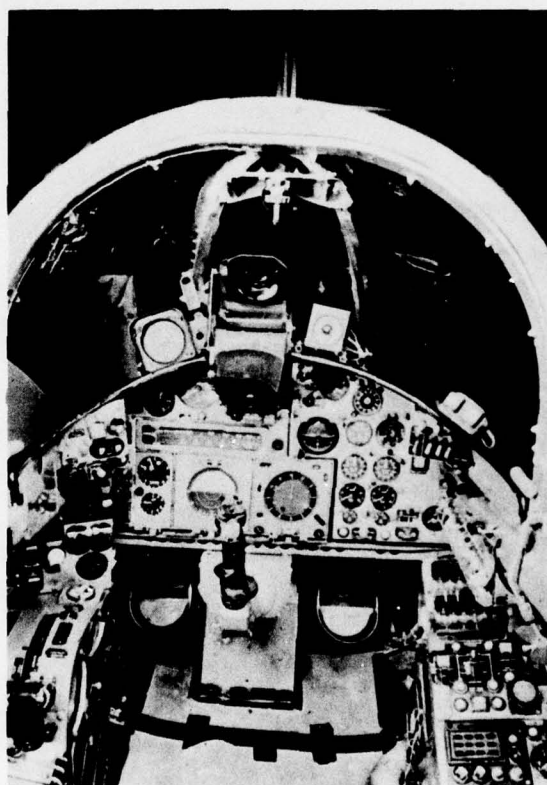


Fig 9 Example of a modern single seat cockpit

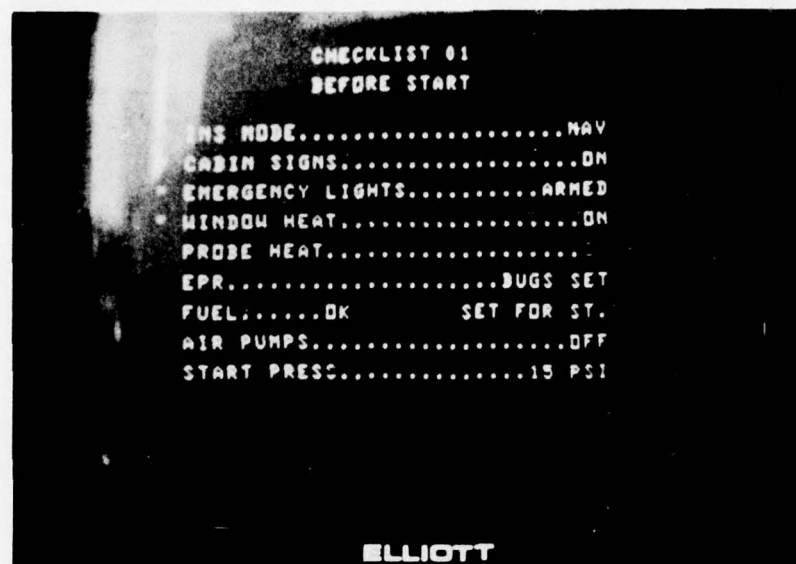


FIG 10 Typical checklist showing the versatility of CRT displays

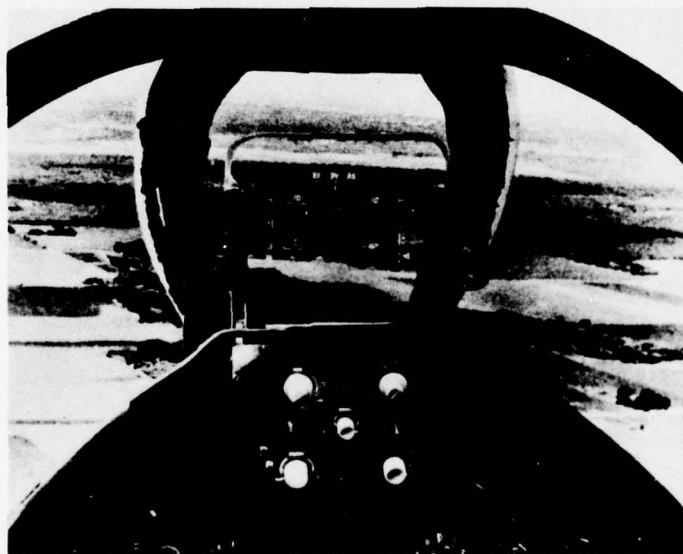


FIG 11 Uncluttered collimated HUD superimposed on the outside world

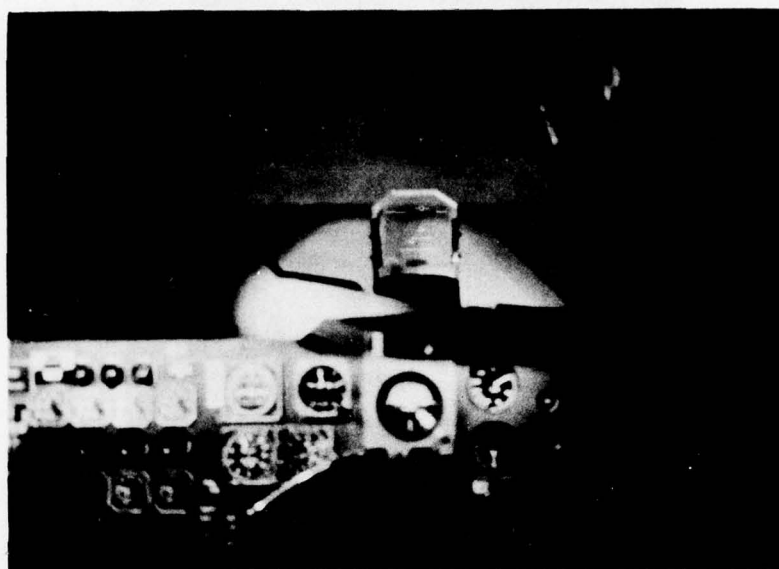


Fig 12 Collimated HUD image in a vibrating environment



Fig 13 An early helmet mounted sight



Fig 14 A helmet mounted display

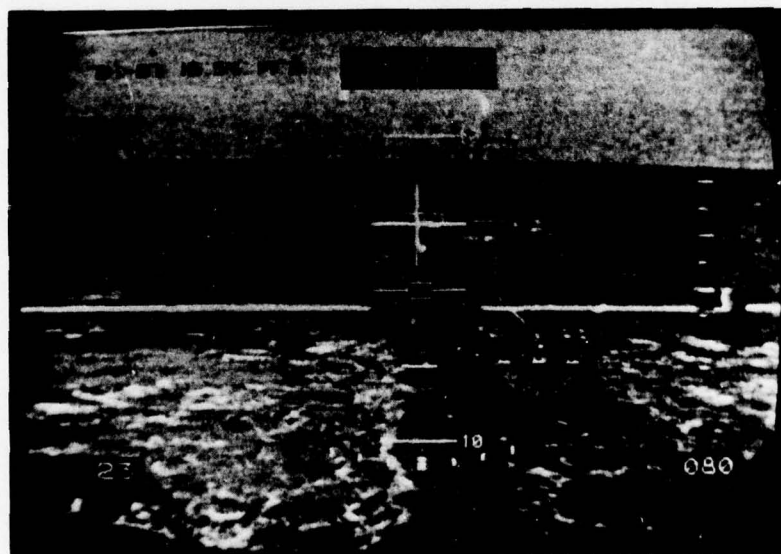


Fig 15 A possible helmet mounted display of low light TV with additional flight information

DISCUSSION

R.A.Chorley, Smiths Industries, Cheltenham, England: In the curves showing how the number of instruments has changed with time, does "Number of Instruments" mean "number of instrument cases" or "number of separate items of displayed information"? The two may be appreciably different, because of the tendency in modern instruments to combine a number of separate items of information, either for operational or for space-saving reasons. The Advanced Cockpit, with electronic displays, is only going to reduce the pilots visual work load if the number of items of information can be reduced by pre-programming. At the moment it looks as though some people are thinking in terms of 50 items of information compressed into 4 CRTs, which will not help anyone!

Author's reply: Yes, only the instrument cases were counted. With regards to the second point of the question, I agree. The advantages of the CRT cockpit display will not be realised unless care is taken to present only the information that the pilot requires and can process in the time available.

CRITIQUE DE L'ECLAIRAGE DES POSTES DE PILOTAGE

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Résumé

Les auteurs se proposent :

- de présenter les normes actuellement en vigueur concernant l'éclairage des postes de pilotage (instruments, tableaux de bord, panneaux de commande);
- de critiquer éventuellement certaines de ces normes ou règles d'usage, en fonction des différentes conditions de vol;
- de décrire des solutions récentes concernant en particulier, les méthodes nouvelles de présentation des informations.

Introduction

Le groupe aéro-médical de l'AGARD a déjà discuté, à deux reprises au moins, des problèmes d'éclairage des postes de pilotage et des présentations d'informations lumineuses colorées fournies au pilote; c'était en Octobre 1967 à Bruxelles, le "Symposium sur l'éclairage rouge ou blanc des postes de pilotage", et en Mai 1972, le "Colloque sur les exigences de la vision des couleurs dans les différentes conditions opérationnelles". Les auteurs ont participé à ces deux réunions.

Lors de la réunion de 1967 avait été discuté, essentiellement, le choix de la couleur des informations fournies au pilote au cours des vols de nuit afin de ne pas perturber l'adaptation à la vision extérieure.

Depuis cette date, le point de vue de l'armée de l'air française n'a pas changé : les avions de combat français (ou construits en coopération avec un autre pays européen) sont toujours munis de deux modes d'éclairage : un éclairage rouge et un éclairage blanc (fourni généralement par des sources ultraviolettes excitant des inscriptions fluorescentes). En effet, si nous reconnaissons qu'un éclairage rouge est générateur de fatigue, surtout chez un sujet hypermétrope ou devenu presbyte, nous sommes toujours convaincus que c'est la couleur qui affecte le moins l'adaptation à la vision extérieure de nuit.

Les normes en vigueur, que nous nous proposons d'examiner, ne concernent que l'éclairage de nuit.

Les nouvelles méthodes de présentation des informations : écrans radars, écrans de tubes cathodiques avec informations monochromatiques ou colorées et toutes les informations autolumineuses, posent des problèmes en vol de jour à très haute altitude. En effet, la luminosité dans le poste de pilotage peut atteindre 70.000 lux ou même davantage.

I- Eclairage classique de nuit

Les normes actuellement en vigueur, pour les instruments de bord et leur éclairage, sont essentiellement les accords de standardisation OTAN (STANAG), élaborés et régulièrement revus par le Groupe de Travail A.I. (Aircraft Instruments) du Bureau Militaire de Standardisation (MAS).

Les normes sont généralement en accord avec les normes ou recommandations nationales correspondantes.

Nous citerons quelques-uns de ces STANAGS :

- 3216 : disposition des principaux instruments de vol.
- 3221 : emplacement des commandes de vol.
- 3224 : éclairage des postes d'équipage.
- 3225 : emplacements des commandes de vol sur aéronefs à voilure tournante.
- 3229 : lettres et chiffres dans les postes d'équipage.
- 3341 : code de couleurs pour marquage des commandes de secours.
- 3436 : code de couleurs pour les plages de fonctionnement des instruments de bord.
- 3643 : traitement anti-reflet des verres d'instruments indicateurs et collimateurs.

Ces normes OTAN ont été préparées à partir de documents ou d'habitudes nationales. Les pays leaders sont évidemment les pays constructeurs d'aéronefs, à savoir principalement les Etats-Unis, la France, la Grande-Bretagne, l'Italie, les Pays-Bas, la République Fédérale Allemande.

Ces recommandations sont suivies, dans toute la mesure du possible. En particulier, en ce qui concerne les STANAGS 3216, 3221 et 3225, il n'est pas toujours possible de les appliquer à la lettre étant donné la place disponible (souvent très restreinte) dans les postes de pilotage des avions de combat.

Le STANAG 3229 fixe les formes et les dimensions des lettres et des chiffres. Il n'est pas non plus toujours possible de l'appliquer, car les dimensions des inscriptions sont plutôt fonction de la dimension du cadran considéré et de la quantité d'inscription à présenter, que de la distance qui sépare le cadran ou le panneau de commande de l'oeil du pilote.

Le STANAG 3341 indique un code de couleurs pour le marquage des commandes de secours, sans toutefois définir ces couleurs de façon précise.

La recommandation qui nous intéresse le plus est le STANAG 3224 A-I ("Eclairage des postes d'équipage").

Il définit :

a)- Les systèmes d'éclairage (minimums imposés) :

- éclairage normal des instruments,
- éclairage de secours des instruments,
- éclairage des panneaux ou consoles,
- éclairage de forte intensité (anti-éclairs).

b)- Les commandes d'éclairage :

- avec réglage de l'intensité lumineuse,
- en éclairage normal et en éclairage de secours.

c)- Les niveaux de luminance :

- pour les informations présentées,
- pour les zones noires (ou plutôt gris très foncé) constituant le fond des cadrans et les zones ne comportant pas d'informations lumineuses,
- pour les aiguilles, drapeaux et autres repères,
- pour l'éclairage anti-éclair.

Pour l'éclairage interne des instruments, les valeurs des luminances recommandées pour la tension nominale d'alimentation (5 V ou 25 V \pm 1%), sont données avec une très grande tolérance \pm 50%. Ceci tient au fait que la visibilité n'est pas seulement fonction de la luminance, elle dépend aussi de la taille et de la densité des informations affichées.

Par exemple, dans le tableau de bord de l'avion franco-allemand TRANSALL, des informations en langue allemande qui ne pouvaient être abrégées formaient des pavés lumineux qui désadaptaient ou éblouissaient les pilotes. Dans ce cas, on a été obligé de diminuer notablement la luminance.

L'expérience prouve d'ailleurs que les minima imposés par le STANAG (que l'éclairage soit interne ou externe, rouge ou blanc) sont trop élevés. Les pilotes n'utilisent jamais la totalité de la puissance électrique mise à leur disposition. Il est à noter que la dernière édition de ce STANAG donne une tolérance de \pm 50% pour l'éclairage interne et n'en prévoit aucune pour l'éclairage externe par projecteurs ou rampes lumineuses sous casquette, ou pour tout autre procédé d'éclairage externe d'un ensemble d'instruments. Ceci nous paraît constituer une lacune.

d)- Les couleurs d'éclairage :

Elles sont parfaitement définies dans le STANAG et sont conformes aux recommandations de la Commission Internationale de l'Eclairage (Publication n°22, 1975), pour les éclairages rouge et blanc.

Le STANAG ne mentionne pas l'usage de l'ultraviolet, peu utilisé en dehors de la France, sans doute à cause d'une légende assez répandue de nocivité. L'ultraviolet pour certains, serait responsable de stérilité! Or, les statistiques prouvent, qu'à catégorie sociale équivalente et pendant des périodes identiques, les pilotes sont ceux qui ont le plus d'enfants!

Les inscriptions en peinture fluorescente DTD 573 A excitées par de l'ultraviolet ne donnent pas vraiment une impression colorée blanche, mais plutôt beige, dont les coordonnées trichromatiques sont :

$$\begin{aligned}x &= 0,540 \pm 0,020 \\y &= 0,440 \pm 0,020\end{aligned}$$

alors que celles du blanc incandescent sont :

$$\begin{aligned}x &\text{ compris entre } 0,480 \text{ et } 0,530 \\y &= y_0 \text{ inférieur ou égal à } 0,05\end{aligned}$$

Les Etats-Unis utilisent souvent le Blanc incandescent muni d'un filtre bleu, ce qui est également recommandé par le STANAG. Le Blanc incandescent, ainsi filtré, ne devient pas jaune, (ou même orangé) lorsqu'on baisse beaucoup la tension des lampes à filament.

Nous pensons que ce "blanc bleuté" (appelé par certains "blanc lunaire") abaisse considérablement l'adaptation à la vision nocturne.

D'autre part, le STANAG ne définit pas les couleurs des drapeaux et autres repères colorés, généralement peints en couleurs fluorescentes, qui ont un excellent facteur de visibilité, quel que soit leur mode d'éclairage : ultraviolet, lumière du jour ou lumière blanche artificielle. Une étude sur ce problème est actuellement en cours en France. Elle devrait aboutir à la limitation de trois couleurs : vert, jaune ou rouge. Ceci devrait éviter tout risque de confusion, l'impression colorée visuelle de ces couleurs variant avec le mode d'éclairage.

Le STANAG 3436 AI donne les couleurs des plages colorées sans définir ces couleurs. Les aéronefs de l'armée de l'air française sont éclairés en rouge et en ultraviolet (les avions de la marine en rouge et en blanc). Lorsque les instruments ont un éclairage interne et individuel, celui-ci est rouge, éclairant des inscriptions faites en peinture fluorescente (DTD 573 A), qui peuvent être également excitées par des projecteurs ultraviolets de lumière de WOOD, de longueur d'onde voisine de 365 nanomètres. Un éclairage blanc ponctuel permet la lecture d'une carte multicolore.

Le STANAG recommande comme éclairage anti-éclat, un éclairage blanc de très forte intensité. Cet équipement n'est pas obligatoire, ce qui nous semble également être une lacune, tout aéronef pouvant occasionnellement se trouver dans une zone de très forte intensité lumineuse.

Le dernier STANAG qui nous intéresse est le STANAG 3543 AI : "traitement antireflet des verres d'instruments, indicateurs et collimateurs utilisés dans les postes d'équipage".

La plupart des instruments de bord sont maintenant munis de "glaces avant" traitées antireflet. Le STANAG fournit des valeurs maximales du facteur de réflexion toléré pour un certain nombre de zones de longueur d'onde dans le spectre visible (de 440 à 665 nanomètres). Le STANAG comporte également, à la demande de la France, une valeur maximale du facteur de réflexion pour la longueur d'onde de 365 nanomètres, caractérisant les sources d'ultraviolet. En effet, il ne faut pas qu'un verre éliminant les reflets dans le visible, réfléchisse davantage de lumière ultraviolette qu'un verre non traité, et que le pilote ou le co-pilote soit alors gêné par des réflexions de ce type. Les fabricants français de verres traités antireflet, savent très bien, actuellement, répondre à cette exigence supplémentaire.

2- Nouveaux procédés d'affichage des informations

Les normes et recommandations que nous venons d'examiner concernaient essentiellement l'éclairage d'instruments, et de panneaux de commandes classiques, éclairés individuellement ou globalement.

Nous assistons actuellement à une révolution dans la présentation des informations fournies au pilote. Par exemple, avec un tube cathodique, présentant des informations en trois ou quatre couleurs, on peut remplacer plusieurs instruments classiques de vol.

L'écran d'un indicateur de situation horizontale (EH SI) peut remplacer un indicateur conventionnel de situation horizontale et offrir également plusieurs autres possibilités : aligner la navigation sur le Nord magnétique ou sur la trajectoire prédéterminée de l'aéronef. Il permet dès à présent la navigation de zone 2 D (2 dimensions) et bientôt la navigation de zone 3 D ou 4 D (3 dimensions + paramètre temps).

Un indicateur à tube cathodique, de situation verticale fournit à lui seul l'ensemble des informations de pilotage correspondant à l'anémomètre - mach mètre, l'altimètre, l'horizon directeur de vol, le variomètre, la radio-sonde et l'indicateur ILS (Instrument Landing System).

On prévoit de monter très prochainement des indicateurs de situation verticale et de situation horizontale sur avions de combat (affichage "tête basse" - "head up displays").

On essaie également de fournir au pilote des informations qui se superposent au paysage qu'il voit à travers son pare-brise. Ce sont pour le moment des collimateurs optiques fournissant une image à l'infini (affichage "tête haute" - "head up displays"). Ils sont généralement éclairés par des lampes à filament. On a essayé de remplacer ces lampes par des diodes électro-luminescentes à l'arséniophosphore de Gallium (Ga AsP), ou par un tube cathodique dont projette l'image de l'écran à l'infini à l'aide d'un collimateur optique. Ces affichages tête haute sont surtout utilisés comme aide à l'atterrissage et au décollage.

Un STANAG, en projet (3648), définira la présentation d'informations électroniques ou optiques; il définira les symboles (formes et emplacements).

D'autres procédés d'affichage sont à l'étude : affichage alpha numériques ou numériques à l'aide de diodes électro-luminescentes, de cellules à plasma, de cristaux liquides. Certains instruments à échelles verticales sont éclairés en électro-luminescence (procédé DESTRIAU).

3- Critique de ces nouveaux procédés

Aucun de ces nouveaux procédés ne répond à la totalité des exigences dans les différentes conditions de vol de nuit ou de jour, à basse ou à haute altitude, en approche ou au décollage.

La gamme de luminance qu'on peut obtenir avec ces procédés se révèle insuffisante pour que les informations soient lues confortablement de jour et de nuit. Seuls les instruments classiques à cadrans peints et à aiguilles mobiles sont lisibles à la lumière ambiante et de nuit avec un éclairage artificiel convenablement choisi.

Il en est tout autrement des informations auto-lumineuses. Pour les tubes cathodiques en particulier, le contraste importe au moins autant que la luminance, que les tubes soient monochromes ou multichromes.

Avec un affichage monochrome, aussi lumineux soit-il (on sait faire des tubes à très haute brillance) toutes les informations apparaissent d'une même couleur, donc identifiables seulement par leur forme ou leur luminance.

Avec un affichage multichrome, les informations apparaissent de différentes couleurs selon un code préétabli, sur un fond généralement de couleur différente, apportant ainsi un très grand avantage sur les présentations monochromes :

- densité d'informations plus importante,
- temps d'acquisition des données beaucoup plus réduit,
- diminution (très nette) du risque d'erreur d'interprétation d'un symbole ou d'une montre,
- possibilité d'un codage supplémentaire par la couleur.

Les couleurs choisies sont limitées à trois, plus éventuellement, une quatrième couleur pour le fond, à cause de la désaturation des couleurs sous éclairage incident élevé, qui augmente le risque d'erreur d'identification. Les couleurs retenues sont définies par leur longueur d'onde équivalente,

- rouge $\lambda \geq 612 \text{ nm}$
- jaune $\lambda \geq 580 \text{ nm}$
- vert $500 \text{ nm} < \lambda < 555 \text{ nm}$

Des travaux concernant les écarts de luminance, les écarts de couleur, les indices de détection et de discrimination, les seuils de perception ainsi que les écarts de chrominance, la sensibilité de l'œil au contraste, en fonction de la luminance de l'écran et le facteur d'adaptation, ont été présentés au 29^e Groupe de Travail AVIONICS de l'AGARD (Technical Meeting on electronic displays - Edimburg, April 1975).

La luminance des informations présentées sur tubes cathodiques doit être réduite de nuit, et la plus élevée possible de jour à haute altitude.

Cependant, si le soleil tombe directement sur le tube, aussi lumineux et contrasté soit-il, ce dernier devient illisible. On a donc été amené à étudier un certain nombre de dispositifs qui empêchent les rayons du soleil de tomber sur la face avant du tube, sans gêner la vision de cette face avant par le pilote. Ce sont des sortes de filtres directionnels, se présentant sous forme d'alvéoles à parois minces, noircies, métalliques, ou en céramique.

L'électro-luminescence (procédé DESTRIAU) fournit une luminance insuffisante pour permettre une lecture par grande luminosité extérieure.

Les cellules à gaz ou à plasma, et les cristaux liquides (ces derniers seraient très lisibles de jour) ne sont pas encore techniquement utilisables sur aéronefs.

Conclusions

Les nouveaux procédés de présentation intégrée des informations sur écran de tubes cathodiques trichromes semblent à priori incompatibles avec l'éclairage rouge que nous préconisons pour conserver au pilote une bonne vision nocturne.

Ils paraissent cependant devoir être de plus en plus utilisés, en raison de la quantité d'informations qu'ils sont capables de fournir et de la rapidité d'interprétation de ces informations par les pilotes grâce aux graphismes multicolores présentés.

Etant donné que les surfaces multicolores sont de petites dimensions, que la luminance des tubes peut être atténuée en vol de nuit, il nous semble que leur utilisation, dans un poste de pilotage dont les instruments classiques sont bien éclairés en rouge, ne devrait pas nuire à l'adaptation à la vision nocturne. Les signaux avertisseurs de prudence, de danger, de mauvais ou de bon fonctionnement, sont d'ailleurs depuis longtemps réalisés sous forme de voyants lumineux conformes à un code de couleurs (STANAG 3370 A.I.).

Une dernière objection d'ordre psycho-physiologique pourrait être avancée. Ces systèmes occupent en effet la partie centrale du champ visuel, ce qui doit limiter l'exploration oculaire et en principe, la fatigue. Il reste cependant à prouver que l'exploration d'un champ visuel réduit, contenant une masse d'informations, n'entraînera pas en fonction du temps une baisse de la vigilance, génératrice d'erreurs.

L'augmentation du nombre des informations oblige à rejeter certaines en périphérie du champ visuel, là où la sensation chromatique est moins fine.

Enfin, nous connaissons bien l'influence de la fatigue sur la perception colorée, aussi bien des sujets normaux que des dyschromates. Ceci implique la nécessité à nos yeux de conserver des normes strictes concernant le sens chromatique; il ne nous paraît pas du tout opportun comme certains le souhaitent d'abaisser les exigences.

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Comparative experimental evaluation of twodimensional and pseudo-perspective displays for guidance and control.

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SUMMARY

The rapid growth of air traffic and the steady increase in aircraft efficiency make higher accuracy and flexibility in guidance and control desirable. Flight manoeuvres requiring an improved performance are among others bended or curved approaches, terrain following and collision avoidance. Conventional displays for accurate flying along a commanded path often incorporate three separate aspects of the 3 D-airspace, showing vertical situation (VSD), horizontal situation (HSD) and profile situation (PSD). As an alternate solution a VSD can be presented to the pilot showing a pseudo-perspective picture of the actual and commanded future track to the pilot. This display may incorporate a synthetic highway in the sky often called channel display, that is HUD compatible.

Since no experimental results comparing the relative merits of both display concepts are available in the literature, several experiments were performed using two display formats which objectively contain a similar amount of information. A fixed base simulation of a Do 28 airplane was used. Performance and eye point of regard measures were recorded as well as subjective ratings.

The results show, that the accuracy of guidance and control is comparable for both display concepts. When predictor information was removed the performance decreased dramatically but to the same level for both displays. Subjective ratings and eye point of regard measures were strongly in favor of the channel display.

INTRODUCTION

The increasing requirements for guidance and control tasks with respect to flexibility and accuracy become obvious when e.g. comparing the conventional Instrument Landing System (ILS) with the newly developed Microwave Landing System (MLS). With the ILS the pilot is forced to intercept the glidepath at a large distance from the airport and to continue with a linear 3 degree descent until touchdown. On the way down he crosses three markers that indicate to him his actual distance from the runway. Main instruments to perform this type of approach are a Horizon and Director Indicator (HDI) showing command information with regard to the glide path as well as an artificial horizon. This is supported by a Course Deviation Indicator (CDI) showing heading and lateral deviations from the localizer.

Applying the Microwave Landing System may basically influence this standard approach procedure. Here the pilot is to a certain degree free to select a proper approach profile and glide path angle. He is especially free to approach from the side and slip in on a curved path. While approaching he can continuously be informed by the ground station about his distance from the touch down point, about the relative position of other airplanes in the terminal area and about other data he needs.

It is obvious that the conventional type of instrumentation mentioned above is not optimally suited for this type of approach. It turns out that pilots hesitate to rely entirely on command information in such complex manoeuvres that give very poor insight into the general situation in the airspace. Situation and predictor displays may offer here remarkable advantages.

Two basically different ways to present such situation information to the pilot are available and will be discussed and compared in this paper.

Twodimensional (2D) display formats :

One way to represent the situation of an airplane in space would be three separated twodimensional views being orthogonal to each other as indicated by figure 1. Here the pilot is confronted with a Vertical Situation Display (VSD) indicating pitch and roll, a Horizontal Situation Display (HSD) indicating heading and range and occasionally with a Profile Situation Display (PSD) that may show trajectories and height information. If electronic means as CRT-screens are applied, situation, prediction and tolerance areas may be shown. Another variable one can make use of is the reference system that may be inside-out or outside-in.

The described display format is characterized by the fact, that the pilot has to scan all three displays sequentially and combine the selected data into one general picture of the actual situation. This implies a considerable amount of eye-scan workload. It was proposed, to avoid the spatial separation by superimposing the three described displays, thus achieving a higher package density [3]. This of course reduces the amplitude of eye saccades that is required for scanning. On the other hand there may result some confusion for the pilot by this superposition. He is supposed to simultaneously "see" himself from behind, from the side and from above and this leads to difficulties in interpretation.

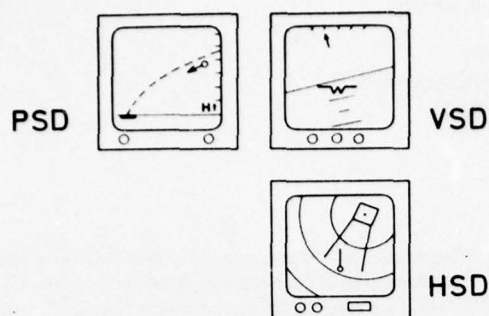


fig. 1 Instrumentation with three two-dimensional display formats. [1]. Indicated are

VSD: Vertical Situation Display
 PSD: Profile Situation Display
 HSD: Horizontal Situation Display.

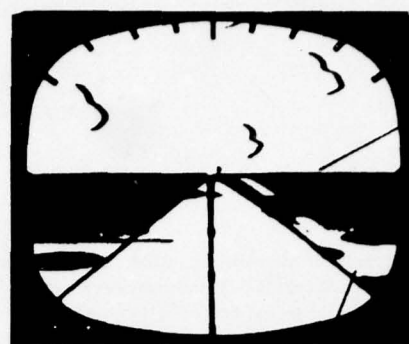


fig. 2 Instrumentation with one three-dimensional pseudoperspective display format. [2]

Three-dimensional (3D), pseudoperspective display formats:

A second way to inform the pilot about his situation in space would be to provide him with an artificial visual sight similar to what he sees during visual flight conditions. In case of an approach to landing this picture mainly would show to him a perspective pattern of the runway, similar to that presented by figure 2. Since this type of information is analog to what the pilot sees during true vision, the meaning is evident without training and can be perceived spontaneously. While it is quite simple to readout an actual flight situation qualitatively from a contact analog display format, it is almost impossible to get sufficient quantitative information concerning the deviation from a desired flight path. If e.g. the runway symbol is far ahead, deviations from the glide path result in only very small angular distortions of the perspective imagery. Such unsymmetries e.g. of the runway trapezoid are hard to read from distance and are no sufficient cues for accurate flying.

Quantitative readings in this case require, that supplementary perspective cues be synthetically added to the contact analog vertical situation display. Several proposals how this could be done are mentioned in the literature and some are shown in figure 3. As a first step an artificial structure symbolizing the command or actual path may be shown in the contact analog scene. This can be implemented using a vertical pole track as applied in the SAAB-Viggen (figure 3a) or a set of pyramid lines (figure 3b). The pyramid lines may degenerate in particular flight conditions to a single line, in which case the perspective impression is lost. This can not happen with the pole track, since poles are arranged redundantly on both sides. This ensures that under any condition at least one perspective cue is visible.

A command path has not necessarily to be materialized as a structure similar to a street or tunnel. An alternative would be to have an artificial leader aircraft symbol, that moves with true perspective, flying at a constant distance in front of the airplane (figure 3c).

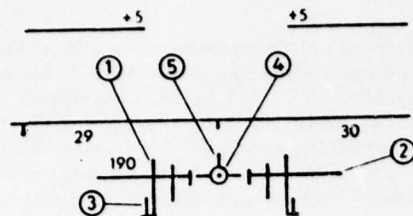
Absolute altitude may be indicated in a contact analog display by vertical poles standing on the ground (figure 5a,d). Commanded height usually is the upper pole end. Absolute altitude may be estimated by comparison with a reference pole of known altitude (3 in figure 3a).

Relative deviations in altitude and heading with respect to a given command path can also be indicated with the desired resolution and still without the use of numerical information. In this case the command path should be given a rectangular structure, the dimensions of which must be known to the pilot. (figure 3e,f)

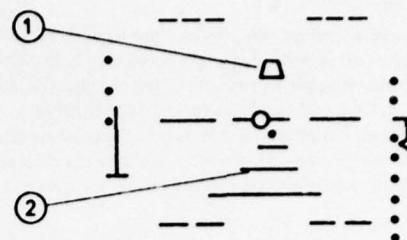
Distance and speed are parameters, which are especially difficult to read accurately from a perspective picture. The quantitative estimation of depth can be assisted by indicating regular segments of the artificial command path structure (figure 3f). If these segments move towards the observer, the well known impression of driving on a street is stimulated. This in addition enables a coarse judgement of the longitudinal speed. A very interesting proposal, that is demonstrated by figure 3g separates the command path segments into one large central and two smaller adjacent tracks, which can move independently from each other. This arrangement allows to simultaneously indicate the commanded speed on the middle track and the actual speed on the two neighboring tracks. If the outer tracks fall behind the command track it is obvious, that the actual speed is too slow and should be increased.

In case of hovering it is essential for the pilot to know exactly where he is with respect to the landing site. While one of course often would use a horizontal situation display for this purpose a rather ingenious solution was found to include also this kind of information into a contact analog vertical situation display. (figure 3h). The proposed display format shows a perspective view of the landing site and superimposed to it the simulated shadow of the hovering aircraft on the ground.

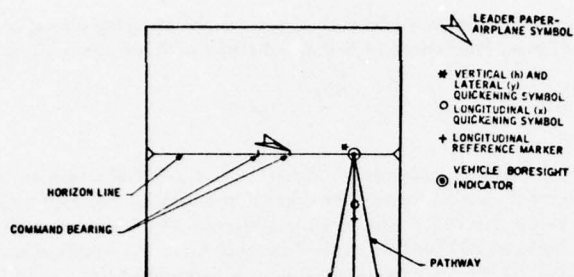
From the examples given it may be concluded, that all parameters needed for accurate flying can be presented in an analog pictorial way in a forward looking display format.



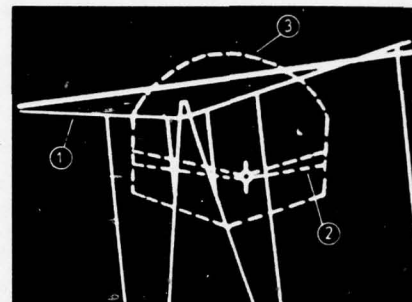
- 1 Pole track
2 Horizon
3 Reference height
4 Speed vector
5 Speed error
- a.) SAAB HUD-Display [4]



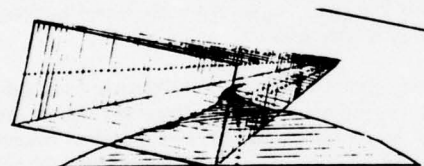
- 1 Runway trapezoid
2 Pyramid lines
- b.) RAE "guidance" HUD-Display [2]



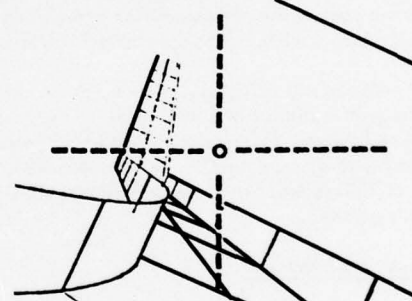
c.) VTOL - Display [6]



- d.) ELANDIS [7]
- 1 Glidepath with outer, middle and inner marker (vertical poles)
2 Predictor
3 Tolerance range



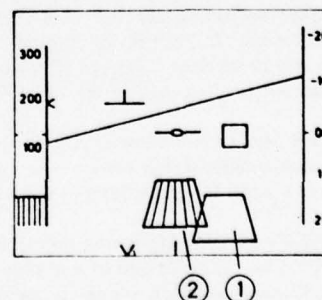
- 1 Command path
2 Predictor
- e.) Display for carrier-landings [9]



f.) Concept of a channel display [8]



- g.) Wide angle HUD-Display [5]
- fig. 3 Perspective cues in vertical situation display formats



- 1 Landing site
2 Simulated shadow of hovering aircraft
- h.) Hovering Display [2]

DEVELOPMENT OF COMPARABLE DISPLAY FORMATS.

As explained in the previous section, information for guidance and control may be presented to the pilot either in two-dimensional or in three-dimensional form. Each of both solutions may have its own advantages. While both display types have proved to be flyable in several simulator experiments and various operational modes [1,8,9,13,14], the relative advantages of both could not be assessed quantitatively from literature. A direct comparison as to the effect of the 2D - 3D parameter failed, because the compared display formats did not contain a comparable type and amount of information. It was therefore concluded, to develop two comparable display configurations. One of these should strictly use two-dimensional cues, while the other one should be of the contact analog type. Display design starts with the definition of some basic criteria:

- both display formats should be given the same panel area in the cockpit
- deviations from the command path should show about the same resolution in both displays
- the reference system should be inside-out for both display formats
- both displays should contain predictor information

In consequence to these criteria there can not always be used true angles in both displays. It has also to be mentioned that display resolution and prediction time are selected arbitrarily based only on some pilot experiments. Both displays may therefore not be optimized with respect to the given task. This optimization process would presume a systematic variation of display parameters, and is not subject of the experiments reported here.

The general situation to be transferred on displays is indicated in figure 4 where an aircraft is shown flying above and to the right of a commanded path that is symbolized by solid lines. Predictions of the actual flight path are shown as dashed lines reaching about 700 meters ahead.

Twodimensional approach

The display that was developed using three two-dimensional formats is presented in figure 5. It consists of a vertical situation display (VSD, upper right) showing a fixed aircraft symbol, scaled reference marks for quantitative readings and an artificial horizon to indicate pitch (θ) and roll (ϕ) angle. Below the VSD a horizontal situation display is arranged. It shows a horizontal baseline of 200 [m] width and three reference marks at 700 [m] distance. The scale factor for longitudinal distance has to be 4 times less than for lateral deviation, since the display area is restricted. A tilted solid line symbolizes the command path being 50 [m] left from the actual position and showing a heading error $\Delta\psi$ of about 10 degrees. From the middle of the baseline, that is from the actual position, a bended dashed prediction line initiates that reaches to the point the aircraft would come to within the next 9 seconds if no further control actions were taken.

The profile situation display (PSD) on the upper left side is constructed along quite similar lines. From the middle of a vertical baseline a straight dashed predictor line indicates the pitch situation and points to the relative altitude the airplane would reach at 700 [m] distance without correcting control actions. A solid line indicates the vertical command path being 50 [m] below the actual position and commanding a climb of about 3 degrees. Again the scale factor for longitudinal distances is four times less than for vertical deviations due to the restricted display area.

When the aircraft is flying a mission, new sections of the command path (solid line) move continuously from right to left in the profile display and downwards in the horizontal display. While new parts are coming in on one side of the displayed time interval, those sections just being passed are simultaneously disappearing under the two baselines (compare scheme in figure 4). Thus the observer always sees his actual and commanded situation and the future track of both up to a distance of 700 meters. Since the predictor lines are dashed, the forward movements can easily be observed and an estimate of speed is possible.

Threedimensional approach

The display format that was developed using perspective three-dimensional cues is quite similar to the one proposed by Wilckens [8]. The basic idea is to provide the pilot with an artificially constructed skeleton of the command path. This structure, that is often called channel or tunnel is given a rectangular shape. While Wilckens proposes to have the borders of the channel extended until they intersect with the picture frame (fig. 3f) here a clipped version as shown in figure 3e is preferred. This results in a concept for a channel display as illustrated by figure 6, where the channel begins at a fixed distance of 100 meters in front of the airplane and reaches another 600 meters into the future. Scaling in lateral direction is 200 meters and in vertical direction 50 meters. Only the lower half part of a tunnel is indicated. Commanded height is reached, when the landing gear of the aircraft levels out with the upper edges of the channel walls.

This clipped version of a channel display can of course not mediate the impression of flying in the channel. The feeling is more like continuously flying towards the channel entrance. On the other hand this solution has the advantage, that scaled reference marks for quantitative readings can easily be brought into the picture.

Translating the general flight situation of figure 4 into the outlined three-dimensional display concept results in a format that is illustrated by figure 7a and in a display zero-position as illustrated by figure 7b. The picture contains six rectangularly arranged reference points which can be used for quantitative readings of pitch and heading angles as well as for the quantitative estimation of horizontal and lateral deviations. In zero-position the command channel fits exactly between the lower four reference points. Three additional points in the lower part of the display are references for the roll angle.

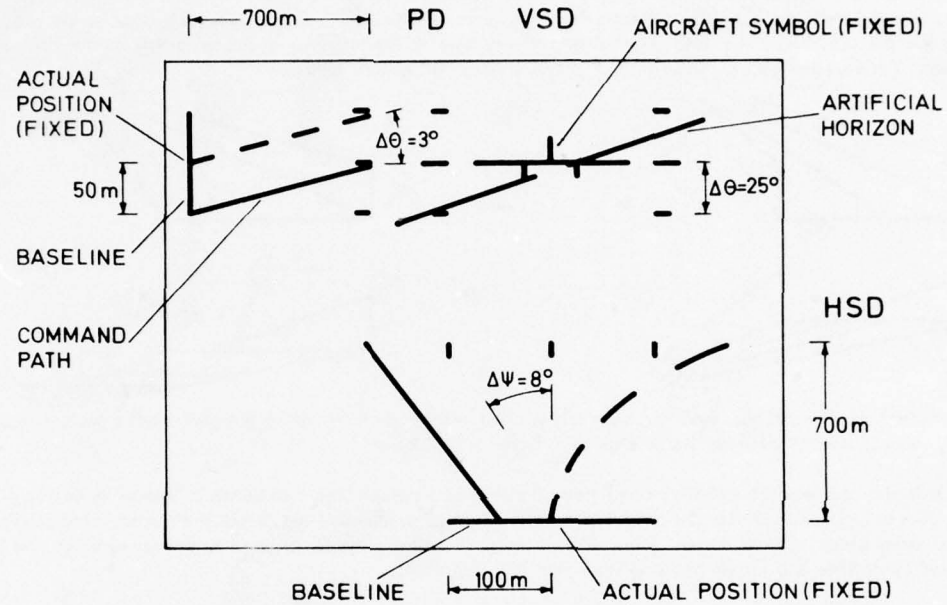
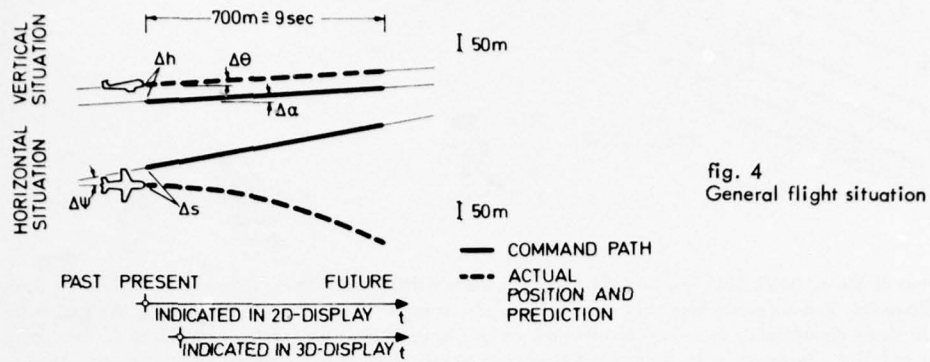


fig. 5 Twodimensional display corresponding to the general situation shown in fig.4

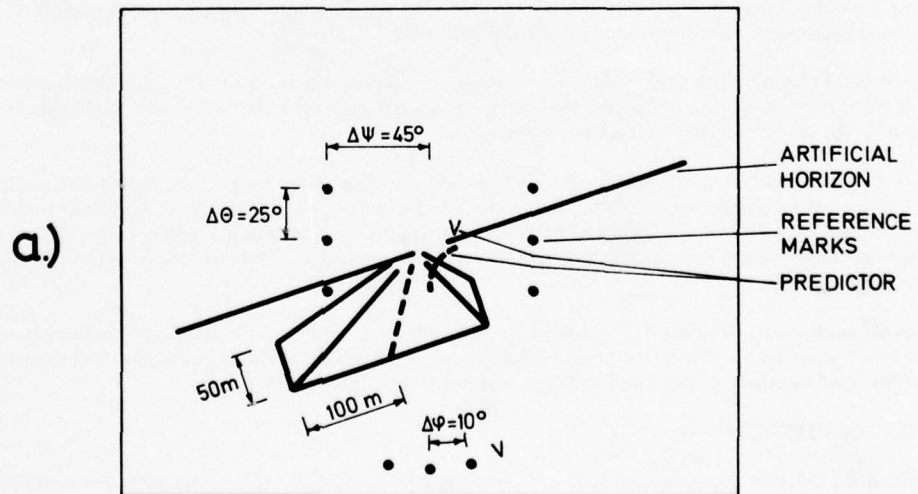
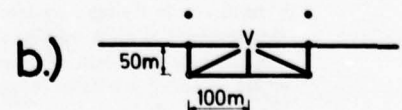


fig. 7 Threedimensional display corresponding to
a.) the general situation shown in fig.4
b.) display zero position



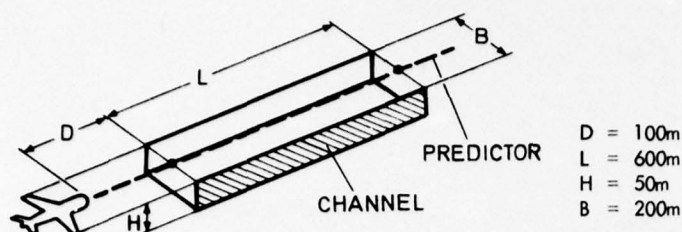


fig. 6 Concept of a channel display

For the implementation of the channel display on a CRT screen, stroke writing techniques were applied. Twelve linear channel elements were lined up. Bended paths had to be approximated by straight lines. In order to perform the rather time consuming calculations in three dimensions, very fast transformations had to be performed. Special hardware for such purposes is described in detail in [10]. Perspective stroke written structures usually stimulate no stable perception and tend to tilt over. In order to avoid these effects some hidden-line removal and area-hatching techniques were applied to the channel. As a comparison between figures 8a. and 8b. shows, the channel inside was given open ends and a dashed center line, while the outside bears regular stripes ①, ②. Intersecting lines were removed ③. These cues turned out to be very effective in stabilizing the picture. Since the dashed centerline moves towards the observer in the same way as the stripes on the channel outside, the observer gets an immediate impression about his actual speed.

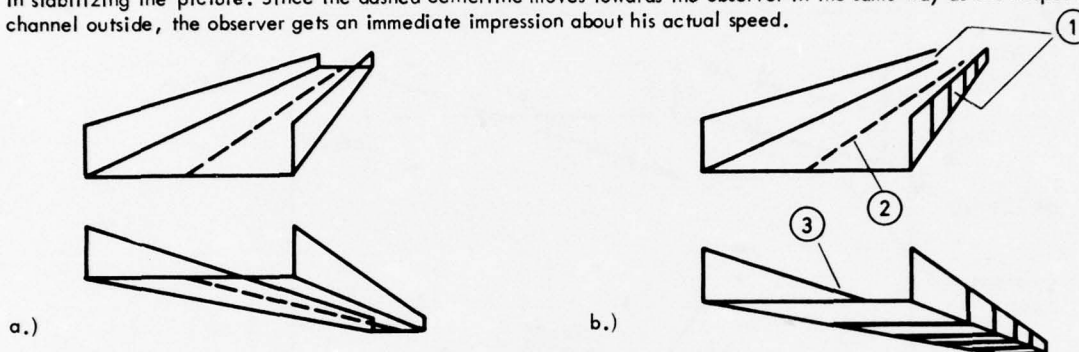


fig. 8 Using hidden-line techniques and hatching of the channel outside to stabilize the perspective picture against tilting over. Figures a.) tend to tilt over while figures b.) are rather stable.

In this 3D-display the predictor of the actual track consists of a dashed line that bends in lateral direction according to bank angles, plus a V-shaped symbol that corresponds to the far end of the channel. From the display zero-position in fig. 7b.) it becomes clear, that in correct position the V-sign should exactly be aligned to the far channel end, in which case the dashed centerline and the dashed predictor line fall together.

EXPERIMENTAL SETUP

During the experiments the subjects were sitting in a modified, fixed base Fouga Magister cockpit. A spring centered stick was used as control element. No pedals were available. The environmental conditions with respect to noise, illumination and temperature were controlled throughout the experiments.

The experimental displays were generated with a special purpose graphical system [12] and displayed on a stroke writing screen in front of the subjects. Above the screen numerals were mounted which were used to give an immediate feedback of results to the subjects during some of the experiments.

The simulation of a Do28-D "Sky servant" was implemented on a EAI/TR48 computer according to equations submitted in [11]. Air speed was held constant at 280 km/h during all experiments. The analog simulation was provided with appropriate initial conditions via a PDP/11 digital computer to simulate the desired mission profiles. This digital computer controlled at the same time the sequence of test runs and the registration of data. Data were sampled at a frequency of 10 Hz and stored on magnetic tape.

A Honeywell oculometer, type Mk IV, was used for eye point of regard measurements. This system allows the eye to move only within a cube inch, therefore a head rest had to be installed. It should be mentioned that subjects were not bothered by this head fixation. A scheme of the experimental setup is given in figure 9.

EXPERIMENTAL EVALUATION

To determine the relative advantages of both experimental display configurations three different experiments were performed. For the comparison of both display formats the following main criteria were selected:

- accuracy in flying a complex mission profile
- assessment of pilot workload by subjective rating and eye-point of regard measures
- quick orientation in space and asymptotically flying onto the command path
- the effect of predictor information in both displays.

Experiment 1 was intended to compare the accuracy in flying a rather complex mission that can be achieved with both displays. The geometry of the selected profile is presented in figure 10 showing the horizontal path in the upper and the vertical path in the lower part of the picture. The whole mission is about 56 km in length and it takes about 12 minutes to fly it at a constant speed of 280 km/h. As may be seen the 19 mission segments contain a holding pattern, curves with climb and descent and altitude transitions of 3 and 6 degrees command path angle.

Experimental design : Ten male subjects with normal or corrected vision, aging between 28 and 38 years, participated in this experiment, all being nonpilots. From these, two groups of five subjects were selected arbitrarily. In the first part of the experiment each group had to fly the test mission several times with one display format until a well trained status was reached. Moderate turbulences in vertical and lateral direction were added to the rudder signals during all test runs. In a subsequent test, each group performed the same task with the other display until again a high training level was achieved. It turned out that the subject found it rather difficult to fly the mission accurately and therefore an extensive training was needed. This may be due to the fact, that nonpilots were used during the experiments.

Instructions : The subjects received a pictorial briefing of both display formats while sitting in the cockpit. The meaning of particular items were explained to them using various flight situations. Subsequently sufficient time was given to them to "play" with the displays.

The subjects were instructed about the mission profile and the purpose of the experiments prior to the first session. Additional explanations were given during the experiment as required. The stated task was to "follow the indicated command path as accurately as possible."

Data registration and analysis : All test runs were registered on magnetic tape. The two "best" runs of each subject were selected for in detail evaluation, according to the criterion minimum average deviation from the command path. The following parameters were selected as performance measures :

- average and RMS deviations from command path
- rudder activities
- average and RMS error in pitch, roll and heading angle

These parameter were calculated for single mission segments and for the entire mission. In addition transitions from straight to curved segments and vice versa were separately analysed in order to determine special effect in this area. For these calculations a time interval of ± 15 sec around the joining point of two segments was used.

An analysis of variance was performed on the data using the ANOVA program of the University of Arizona. This analysis was based on the following model :

random factor :	5 subjects	(V)
fixed factor :	2 test series	(R)
	2 display formats	(A)
	19 mission segments	(M)
	2 runs per subject	(W)

Effects were accepted as significant for this study if $p \leq .05$ and only those are discussed below. The detailed analysis was confined to display effects. Higher order interactions were generally not significant and were not further analyzed.

Results : Display-sequence interactions turned out to be not significant. The same is true for the influence of subjects. No unsymmetrical transfer effects could be observed.

Average deviations from the command path in height as shown in fig. 11a indicate, that the 3D display was flown 7 to 9 [m] too high depending on the mission profile. As compared to the actual picture on the screen, this corresponds to about one fifth of the channel walls. In contrast to this finding, the 2D display shows a consistent error in height of only 2 [m] over the whole mission. It is supposed, that the constant error made with the 3D-format may be evoked by visual perception since the channel does not form a symmetrical Gestalt in vertical direction. This may unconsciously mislead subjects as to the channels zero position. A redesigned channel could supposedly avoid this systematic error, so that both formats would show comparable accuracy in altitude control.

The average lateral deviation from the command path during straight mission segments is for both display formats statistically the same (see fig. 11b). In curved mission segments however this is no longer the case. Here the error made with the 3D format is 35 [m] and this is much higher than the value of 3 [m] found for the 2D display. It should be added, that with the channel display the error is always directed towards the inner side of the curve independent on whether a right or a left turn is made. One interpretation of this finding could be, that with the channel display the subject really feels like driving on a road. As trained from his daily experience, he approaches the inner border of the street when flying a curve and leaves the center line. This would be an explanation for the above mentioned error of 35 [m], which corresponds to about 1/6 of the displayed channel width. While of course according to the stated task (fly as accurate as possible) the 2D format is far superior to the 3D format with respect to lateral accuracy, the interpretation made above should be considered before a final judgement is made.

As another performance measure the variance of the radial deviation from the command path was calculated. The results as presented in figure 12a show, that only during transitions from curved to straight mission segments the 3D display turned out to be significantly better than the 2D format. Other segments show the same tendency but do not reach the required level of significance. To support this finding the error variance of the roll angle is presented in figure 12b. Again there is no significant effect due to the display format as long as straight mission segments are concerned. During curved flight segments

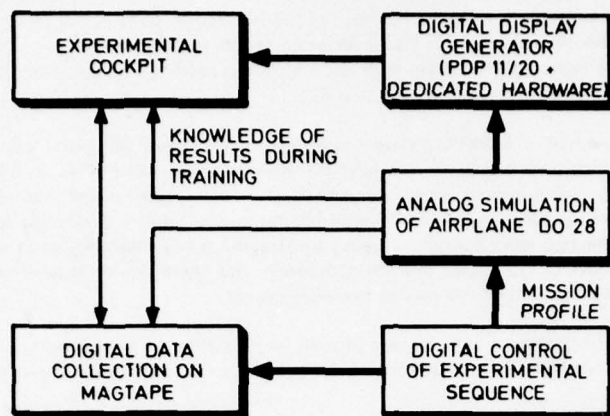


fig.9 Scheme of the experimental setup

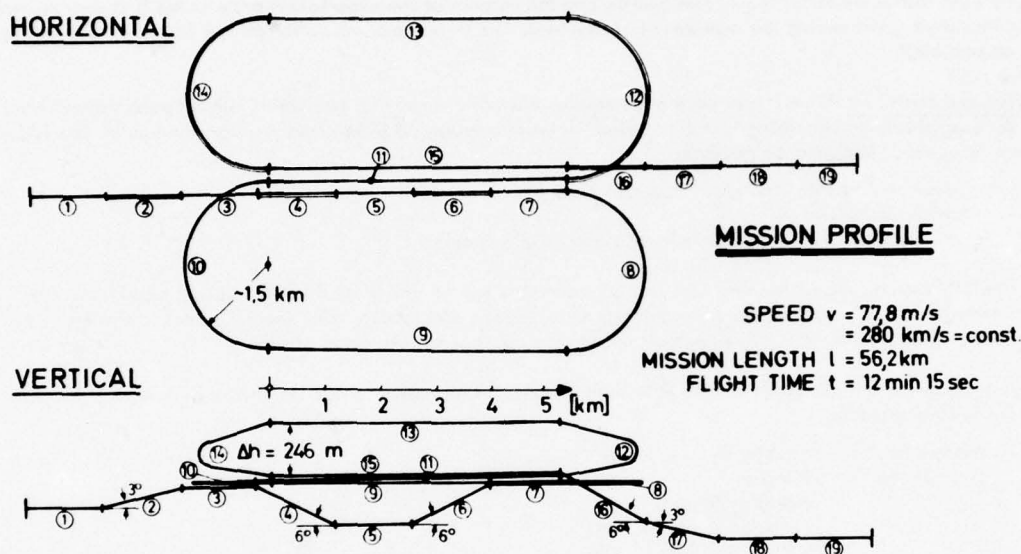


fig.10 Mission profile that was used in experiment no.1

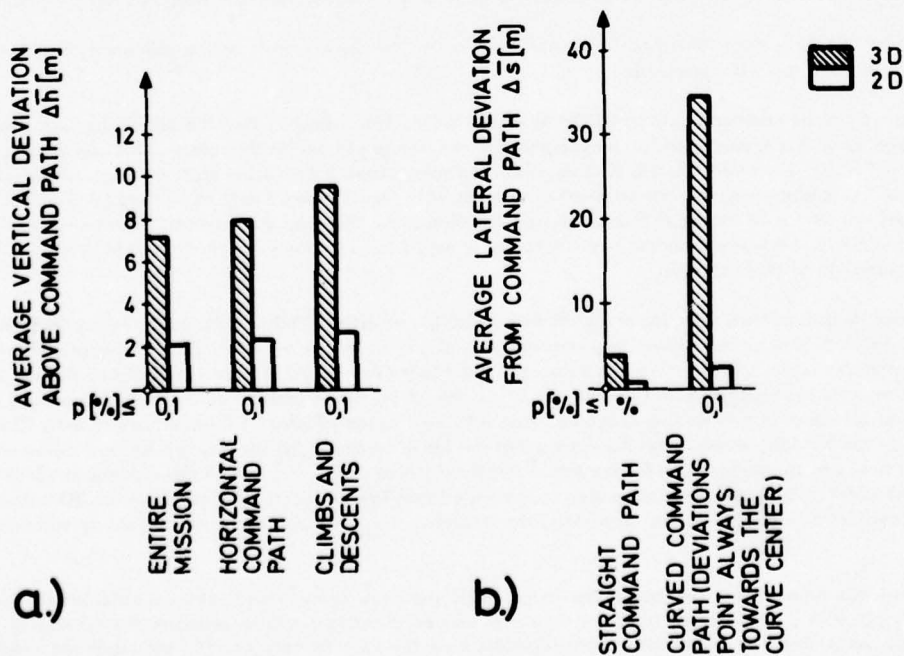


fig.11 Average deviations from the command path in vertical (a.) and lateral (b.) direction.

a significantly higher roll angle variance was found for the twodimensional instrumentation. Both results, the higher roll angle variance and the higher variance of radial deviations found for the 2D format lead to the conclusion, that subjects have more complete command over the aircraft with the channel display, at least when flying curved paths. Obviously a higher amount of lateral stick activity is applied with the 3D format in order to achieve this improved behaviour in flying (see figure 12c).

Responses to the display evaluation questionnaire indicate, that subjects feel more stressed by flying the 2D display and thought the accuracy of this format to be superior (Questions 1, 2). The channel on the other hand was considered to be far more realistic (Question 3) and to permit a far quicker and simpler orientation (Questions 4, 8). The display quality was generally judged to be fully sufficient. Four complains were made with regard to the vertical position presentation in the channel display. This reflects the objective measures of the average vertical deviation.

Display format	3D	2D
1. Which display format could you fly more accurately	3	6
2. Flying with which display format did stress you more	3	6
3. Which display format gave you a better feeling of realism	8	1
4. Which display format gave you a quicker orientation in critical situations	8	2
5. Which display format did you like more	6	3
	Yes/No	Yes/No
6. Was vertical position information adequately presented	6 4	10 0
7. Was lateral position information adequately presented	9 1	10 0
8. Did you always know your actual situation in space (climbing, sinking, banking) while flying the mission	8 2	3 7

Table 1. Display evaluation questionnaire. The table shows the number of answers received from 10 subjects.

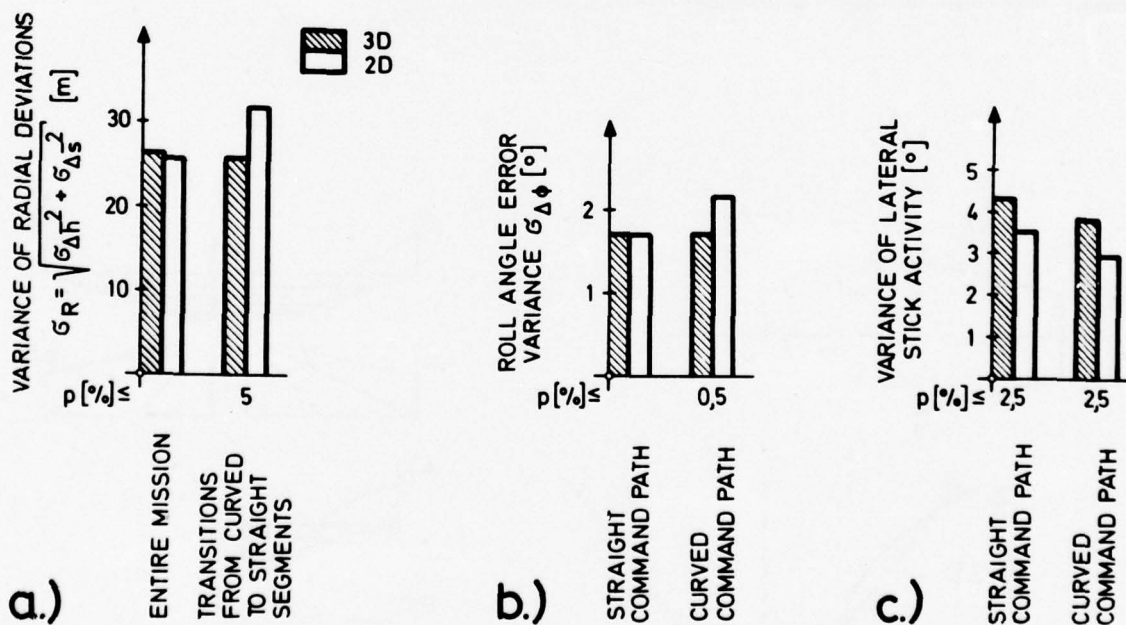


fig. 12 Significant results from experiment no. 1

- a.) variance of radial deviations
- b.) variance of roll angle
- c.) variance of lateral stick activity

Experiment 2 was intended to determine quantitative data concerning the speed of orientation in a randomly presented flight situation. A second purpose of this experiment was, to examine whether a different flight strategy was applied depending on the selected display format.

Experimental design : Two groups of two subjects, which all had already taken part in the first experiment, were selected. The criterion of selection was the homogeneity of control performance. The experimental task was to fly onto a commanded path, starting from a random position. At the beginning of the experiment, the subject was sitting in the cockpit, looking on a blanked screen. Suddenly the display would appear, showing the aircraft in a random position relative to the command path. The stated task for the subjects was to "fly back to the command path as quickly and asymptotically as possible until virtually zero deviation is reached." In order to do so, the subject had first to perceive and interpret the randomly presented situation and subsequently initiate convenient control actions. This experimental design simulates the situation when an observer casually is monitoring a display and suddenly is forced to take over to manual control.

Two experimental series were performed. The first one analysed the performance in flying onto a straight command path starting from four randomly selected initial condition (A I, A II, B I, B II) as shown in figure 13. Each subject had to fly 50 approaches of this type. A second experimental series tested the performance when flying onto a curved command path. In this case only two different starting conditions (A III, B III) were randomly presented and 20 trials were asked from each subject.

Data registration and analysis : Horizontal and lateral deviation were registered as a function of time. Characteristic curves are presented in figure 14 for both displays and all four subjects. In addition the radial RMS deviation from the command path ($\int (\Delta s^2 + \Delta h^2) dt$) was calculated for each trial and the scores were plotted as shown in figure 15.

Results : As may be seen from figure 14 a smooth and quick approach to the command path could be made in all cases. It appears, that the twodimensional format induces a tendency to overshoot in lateral direction before finally approaching the command path asymptotically. This behaviour very seldomly was observed with the 3D-display. Quick orientation turned out to be simple with both formats. After some training almost no control reversals could be detected. Subjects reported some difficulties to fly exactly onto the curved command path using the 3D display. Sometimes they couldn't achieve to maintain exactly zero deviation over longer periods. This caused some tendencies to oscillate. The reason may be that the dynamics of the predictor are much slower with the channel display as compared the 2D-format. The resolution of the predictor information is worse, because the perspective presentation means a reduction of size for objects far away.

The error scores indicated in figure 15 show no obvious differences in total performance. It can be observed, that after about 15 to 20 trials the subjects reached a relatively stable level of performance which was similar for both displays and all subjects. It is therefore concluded from this experiment, that both displays provide quick orientation for trained operators and that both show about the same accuracy in flying back onto a command path from a random position. The strategy by which these equal scores are achieved is slightly different. With a 2D format there is a permanent tendency for overshooting while the channel yielded quite consistently an asymptotic approach.

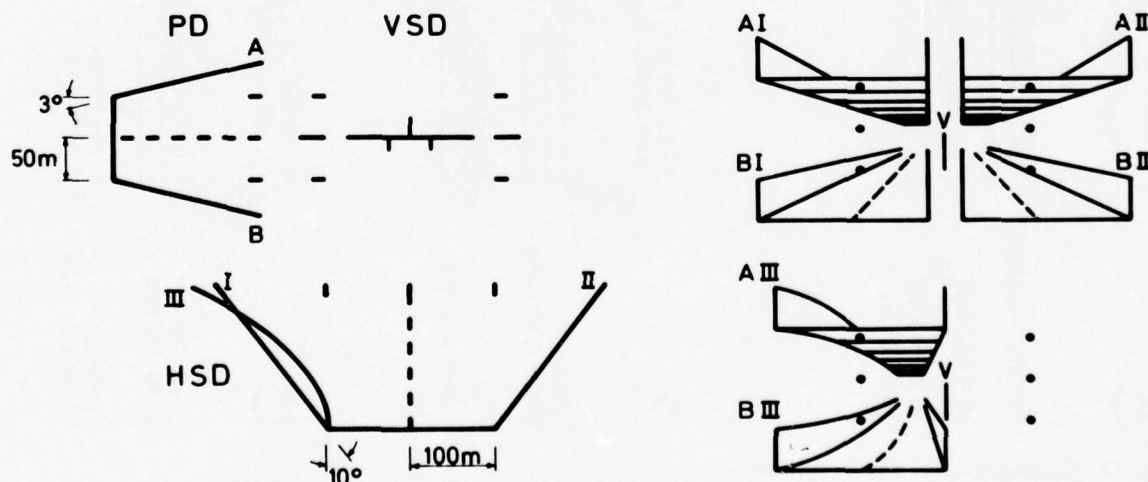


fig.13 Initial conditions used in experiment no.2

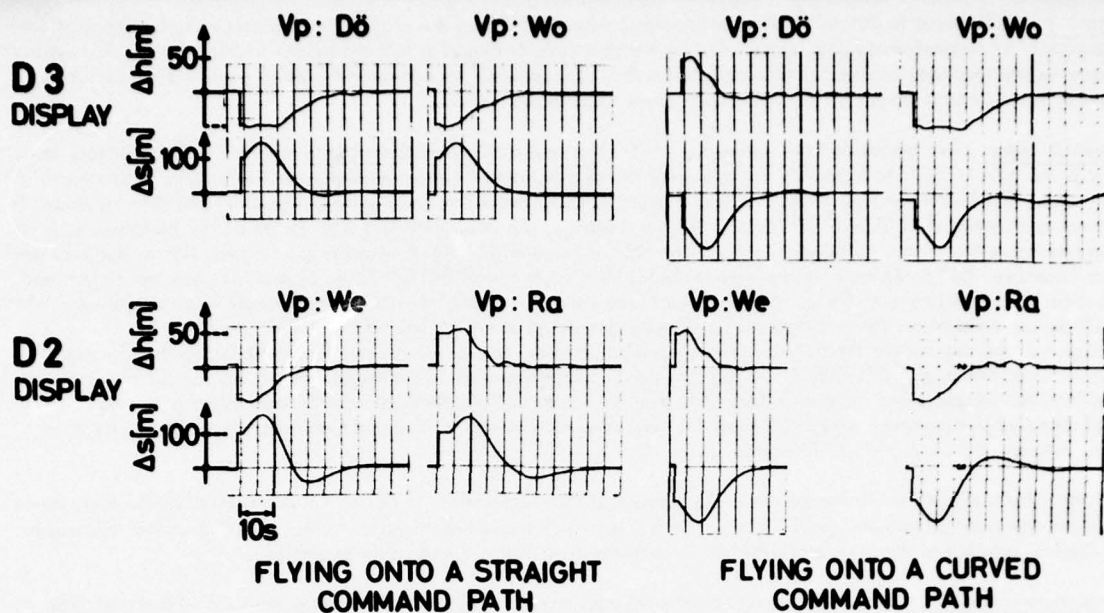


fig.14 Approaching the command path from a random position. Indicated are typical time records for both displays and for straight and curved mission segments.

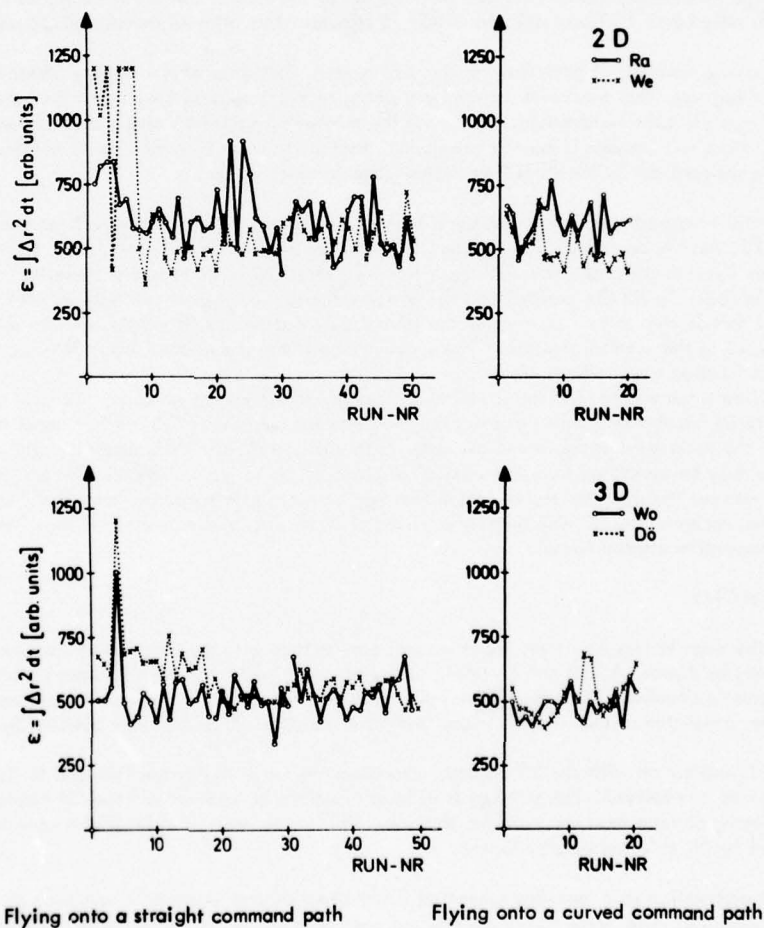


fig.15 Squared error scores for approaching the command path from random positions.

Experiment 3 was intended to determine the display effect when stabilizing the airplane against heavy turbulences. A second purpose of this experiment was to assess whether the performance degrades if the predictor information is removed from both experimental displays, or whether the predictors could be substituted by extensive training. To round the picture up, eye point of regard measurements were taken during these experiments.

Experimental design : Two groups of three subjects, all of which had already participated in the first experiment took part in this experimental series. Each group had to stabilize the airplane against heavy turbulences while flying along a straight command path. The turbulences were derived from a gaussian noise generator (3d B point at 0.15 Hz) and directly added to the vertical and lateral stick signal. The amplitude of turbulences was adaptively adjusted to the actual performance level according to figure 16 : When flying within a band of ± 25 [m] around the command path, the subjects had to stabilize against 100 % turbulences. This could only be managed if the subjects made use of the full range of possible stick movements and applied them immediately and in the correct direction. Any control reversal inevitably would cause large deviations. When flying off the command path, the turbulences immediately decreased down to about 10 % at 250 [m] error. In a first part of the experiment the subjects of each group had to fly several 30 minutes runs until for each individual a stable level of performance was reached. During the second subsequent part of the experiment, predictor information was removed from both displays and another series of test runs was made until again each subject reached an individual and stable maximum of performance. When subjects were well trained, eye-point of regard measurements were registered in 3 minutes intervals for all experimental conditions.

Instructions : The subjects were informed about the purpose of this experiment. It was especially pointed to the fact, that the length of the test runs (30 minutes) would require the full attention and a high level of motivation. The stated task was to "fly as close as possible to the command path and to compensate deviations as quickly as possible."

Data analysis and results : All test runs were looked over and for each subject the 15 minutes interval with the smallest deviations was selected for further inspection. Tolerance bands around the command path were defined and it was determined how often and how long subjects were flying outside certain borders. Both measures yield very similar results, therefore only the number of violations for various tolerance bands are plotted in figure 17. It may be seen, that the indicated means are based only on 3 runs which are symbolized by small dots. Nevertheless the behaviour of subjects is remarkably consistent and no large differences can be observed with respect to the display factor. It should be realized that e.g. a tolerance of ± 30 [m] is only about 10 times violated within 15 minutes. This interval corresponds to about $\pm 1/6$ of the indicated channel width.

When removing predictor information, again only a minor influence of the display factor could be observed. The more interesting thing was, that even with extensive training no subject could ever reach the same score as with predictor. The deteriorations are quite remarkable, increasing the number of violations of a given tolerance band at least by a factor of 100 [%]. From these results it may be concluded, that predictor information could neither be adequately substituted by the twodimensional nor by the threedimensional display format alone.

Eye point of regard measurements show a basically different scanning behaviour as exemplified by representative records in figure 18. As may be expected, with the 3D format the pilot is steadily looking to the center of the channel. At and around this fixation point he finds all information he needs. With the twodimensional format (including predictor) the subject sequentially checks the profile and the horizontal situation in a surprisingly regular manner. Fixation times on the horizontal format used to be longer since the lateral axis was more difficult to control than the altitude. Almost no attention was paid to the vertical situation. The average amplitude of saccades subtended an angle of 8 degrees and about 40 changes in fixation occurred per minute.

When predictors were removed, the scanning pattern of the 3D-format remained virtually unchanged only that it becomes more scattered because of larger deviations of the observed channel. With the 2D format however the removal of the prediction in the horizontal plane forced the subjects to entirely modify their scanning behaviour. Since altitude situation could now only be picked up from the vertical display, all three parts of the display had to be scanned sequentially. This of course reduces the time and the attention that can be spent to a particular part of the instrumentation. The subjects reported, that scanning the 2D display over a period of 30 minutes was extremely tiring. No complains of this kind were made for the perspective display format.

CONCLUSIONS

From the experiments described above several conclusions as to the relative advantages of two- and threedimensional displays may be drawn. A first and certainly surprising result was, that both displays permitted about the same accuracy in flying a complex mission. With the channel display systematic errors in maintaining a commanded height were observed. This mistake was attributed to the unsymmetrical Gestalt of the channel and may be avoided by a new design.

When flying curves with the 3D display, a tendency to leave the center line and to fly along the inner border of the channel could be observed. This strategy is different from the behaviour with the 2D display. Obviously subjects really felt like flying along a road and behaved that way. This means that, in spite of the same instruction, strategy of flying was determined by the selected display format.

Quick orientation in a randomly presented flight situation and asymptotic approach to the commanded path was possible with both displays. After some training almost no control reversals did occur. When approaching a curved channel a tendency to oscillate around the zero position could be observed with the 3D display. This may be due to the fact, that in the perspective picture the predictor shows smaller movements and slower dynamics than in the twodimensional formats. Errors are therefore harder to read.

When predictor information was removed, performance degraded to the same amount for both displays. This decrease could not be compensated by extensive training. This means that no adequate mental model of the controlled process could

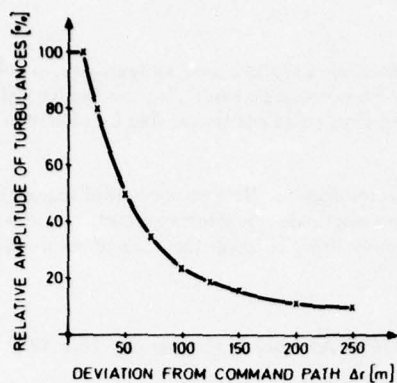


fig.16 Amplitude of turbulences as adapted to the actual deviation from the command path.

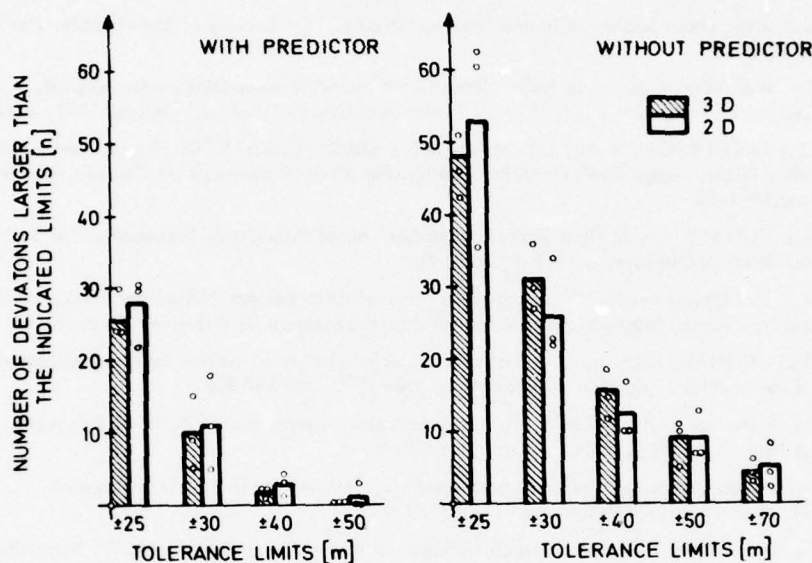


fig.17 Number of violations of a given tolerance band during a 15 minutes run.

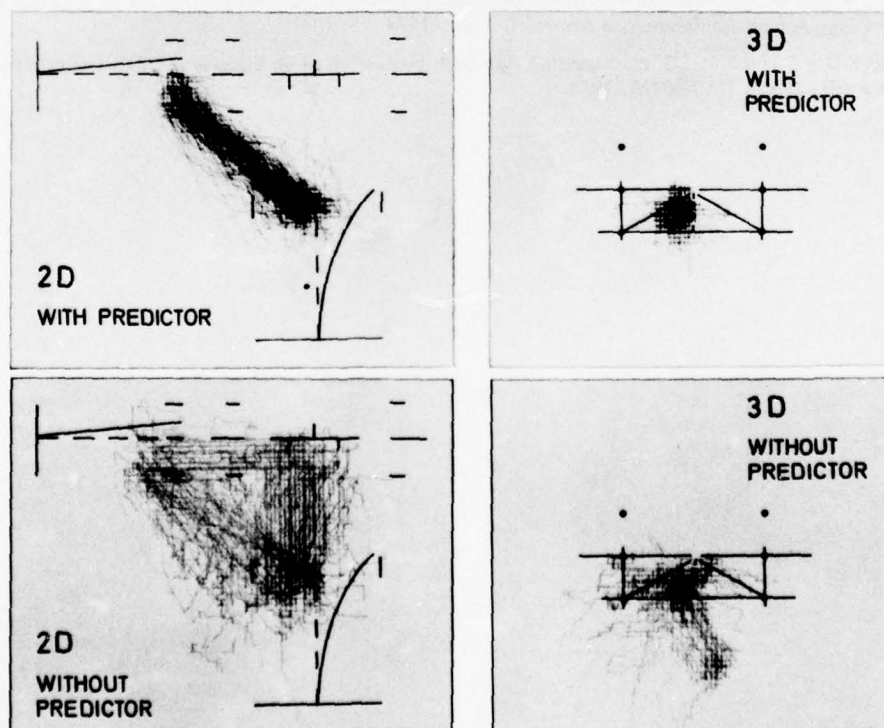


fig.18 Characteristic 3 minute records of eye movements during experiment no.3 for a well trained subject.

be built up by the subjects without predictor information.

Subjects preferred flying the channel because it gave a better feeling of realism and, subjectively, a quicker orientation in critical flight situations. On the other hand while subjects felt more stressed when flying the twodimensional display, they had the impression to be more accurate with the 2D format. This feeling could not be verified by objective performance measures.

Eye-point of regard measures were strongly in favor of the channel display. Here no sequential scanning as with the 2D format was necessary and the required eye saccades had a far lower amplitude. Subjects reported, that the sequential, large amplitude scanning of the three twodimensional formats was extremely tiring if longer intervals of observations were required.

REFERENCES

- [1] Displays for Approach and Landing of V/STOL aircraft. AGARD Advisory Report No.51, Nov.1972
- [2] V/STOL Displays for Approach and Landing, AGARD Report No.594, July 1972
- [3] BEYER, R.; Display für Steillander; DFVLR-Nachrichten, März 73, S.382-384
- [4] FRIEDBERG, U.; Basic about Scale one to one Head-up Display, The Society of Experimental Test Pilots, S.77-85, 1972
- [5] LaRUSSA, J. A.; A Multi-Purpose Wide Field, Three Dimensional Head-up Display for Aircraft, Agard Conference Proceedings No.96 on Guidance and Control Displays, Oktober 1971, p.18.1-10
- [6] CUNDARI, F. L.; NICHOLSON, R. M.; GURMAN, B. S.; BAKER, C. A.; VTOL Displays and Controls for All-Weather Flight, Agard Conference Proceedings No.55 on Problems of the Cockpit Environment, Nov.68, p.19.1-28
- [7] HOLSTEIN, W.; ELANDIS - A Vertical Situation Display, Agard Conference Proceedings No.167 on Electronic Airborne Displays, p.13.1-7, April 75
- [8] WILCKENS, V.; Zur Lösung der Flugführungsprobleme vornehmlich bei der Nullsicht-Landung mit der echt-perspektivischen, bildhaft-quantitativen Kanal-Information; Dissertation, TU Berlin 73
- [9] WULFECK, J. W.; PROSIN, D. J.; et al; Effect of a predictor display on carrier landing performance - Part I.: Experimental evaluation, Dunlap Ass., June 1973, AD 767 982
- [10] KRAISS, K.-F.; A Digital 4x4 Matrix-Multiplier for Computer Graphics with Realtime Dynamics; SID Symposium Digest of Technical Papers, May 1974
- [11] Systemtheoretische Auslegung eines digitalen Autopiloten am Beispiel der DO 28-D Skyservant. TB 000 D 701/71, Bodenseewerk Gerätetechnik GMBH, 1971
- [12] KRAISS, K.-F.; Dynamische 3D-Informationsdarstellung auf Bildschirmen; Bericht Nr.17, Forschungsinstitut für Anthropotechnik, Meckenheim b. Bonn, Juni 74
- [13] MURPHY, M. R.; et al; Simulator Evaluation of Three Situation and Guidance Displays for V/STOL Zero-Zero Landings; Annual Conference on Manual Control, 1974
- [14] TALBOT, P. D.; STINNETT, G. W.; Landing Approach Evaluation of an Integrated CRT Display for general Aviation Aircraft, NASA TM X-3096, 1974

DISCUSSION

R.Bruns, Human Factor Branch, Code 1242, Pacific Missile Test Center, Point Muger, Calif., USA 93042: What plans are there for future development and flight listing of the three dimensional channel display?

Author's reply: To my knowledge there are currently very few 3 D-type displays operational. Displays with perspective cues are in the Harrier and the Saab-Viggen. Kayser has developed a similar display. At the time being there is very little done in testing and developing guide displays.

THE MALCOLM HORIZON

by

K.E. Money, R.E. Malcolm and P.J. Anderson

Summary

The Malcolm Horizon is a bar of light which shines across the instrument panel of an aircraft cockpit and which is driven by motors so as to move in a manner corresponding to the real horizon outside the aircraft. The motion is controlled by servo-motors which are driven by signals derived from the gyro platform of the aircraft. A series of simulator trials and flight trials have been carried out on the device in an attempt to evaluate it and further develop it, and to evaluate aircrew performance while using the device. The trials showed that the bar of light is very compelling, is in constant view regardless of where the gaze may be directed and does not interfere with the normal reading of the instruments. All of the pilots who have flown with the Malcolm Horizon reacted positively and would welcome the addition of this device to the cockpit. It is expected that a license for its manufacture will be granted prior to this conference, and that the device will be available commercially by late 1978.

The Malcolm Horizon is a bar of light which shines across the instrument panel of an aircraft cockpit and which is driven by motors so as to move in a manner corresponding to the real horizon outside the aircraft. The motion is controlled by servo-motors which are driven by signals derived from the gyro platform of the aircraft. The rationale behind this device and some details about its construction were given at a previous AGARD meeting. (1) The purpose of this paper is to describe some of the tests which have been done with the Malcolm Horizon in attempting to evaluate and develop the device and to evaluate aircrew performance using the device.

Simulator Trials

The Malcolm Horizon was first tested for two weeks in a Canadian Forces Sea King helicopter simulator. Some 35 Sea King pilots, as well as a number of pilots of other types of aircraft flew the simulator for various times ranging from 15 minutes to three hours. During these trials, a whole range of in-flight emergencies were simulated, both with the horizon bar on and with it off. It was determined that the improvement in the performance of the pilots brought about by the Malcolm Horizon was roughly equivalent to that produced by the Automatic Stabilization Equipment (ASE) normally used in this helicopter. That is to say, the reduction in the errors in heading, altitude, airspeed, pitch and roll when comparing performance with the Horizon off to performances with it on was equivalent to comparing the pilot's performance with the ASE off and with it on. The pilots report that with the ASE off, this helicopter is very difficult to fly accurately and feels something like an inverted pendulum which always tends to fall over.

During simulation of rapid sequences of in-flight emergencies, it was noted that the pilots made many fewer errors in heading, airspeed and altitude with the Horizon on than with it off, yet when debriefed, they all said that they were unconscious of its presence during the emergencies. This is of course what one would expect from a device which provides information along essentially subconscious channels with peripheral vision.

These trials also showed that the bar of light must be centered in front of the pilot, rather than centered on the roll axis of the aircraft. This is because the pilot perceives the roll axis of the aircraft to be directly in front of him, even in a wide cockpit with side-by-side seating. If the bar of light is centered in the middle of the instrument panel, then when the aircraft rolls to the left, the bar will rotate clockwise, causing the pilot in the left hand seat to think his nose is low, while the pilot in the right hand seat will think that the nose is high.

The Horizon was subsequently tested in a Boeing 747 simulator belonging to Air Canada. This airline was interested in the device as an aid during turbulence penetration. It was flown by several senior pilots, including the airline's chief pilot. They felt that it was a most compelling display, and it clearly did not interfere with the pilot's ability to read his other instruments. They indicated that the device merited further testing and arranged for a flight trial in one of their DC8 aircraft, which will be described later.

Flight Trials

The Malcolm Horizon was first flown in a CH 135 'Huey' helicopter belonging to the Canadian Armed Forces. The control signals were derived from a vertical gyro platform mounted in the aircraft especially for the trials. It was found that if the bar was projected onto the windscreen in the manner of a large 'heads up' display, then the pilot tended to try to line it up with the top of the instrument panel. Since the panel top was curved, the pilot tended to fly with 'one wing down'. If the bar was projected onto the instrument panel itself, then it was very easy to see, and provided good cues even when the pilot was looking out the window.

During one flight, at night over a large open body of water (Lake Ontario) the pilot was asked to fly towards a single light, probably a ship, off in the distance. The co-pilot monitored the pilot's flying by staying on instruments, and the Malcolm Horizon was off. As expected under such circumstances, the pilot who was flying towards the light quickly became disoriented. He apparently tried to track the autokinetic motion of the spot of light, and was unable to adequately control the aircraft, forcing the co-pilot to take control. This was repeated several times to impress each crew member that adequate control could not be maintained by looking outside under these circumstances. The Horizon bar was then switched on, and the pilot was asked to repeat the test. The instrument panel on the 'Huey' is quite small, and is located down around the pilot's knees, yet with the bar of light shining on it, the pilot had little trouble maintaining his heading, pitch and roll to within 2° , and his airspeed to within 5 knots for more than 5 minutes, all the while continuing to stare at the same remote spot of light.

The device was next flown in a Canadian Forces 'Otter', a STOL aircraft. The two pilots who flew the device reported that it made instrument flying 'almost as easy as flying VFR'. They felt that the device would be particularly valuable during whiteout landings and glassy water landings (procedures that are done by instrument flying in this aircraft), and that it would provide a welcome reduction in workload during long range bad weather flights.

The device was next installed in a DC8 belonging to Air Canada, and tested during a check flight subsequent to a major overhaul, during which the aircraft is put into a number of unusual attitudes and manoeuvres. The pilot reported that the display is very compelling, and would doubtless be of great assistance during turbulence penetration. This would be so even when attitude hold had been selected on the auto pilot, since under these conditions, the pilot must monitor the performance of the auto pilot to ensure that it is doing its job properly. Apparently during episodes of severe turbulence, especially in the long-bodied airliners such as the DC8, the pilot can be bounced around so badly that he cannot read his instruments (let alone fly by them).

The device was next installed in a Canadian Forces Sea King Helicopter, and flown operationally for one week. The report of the squadron project officer contains a statement from one of the pilots who evaluated the device. His comments are reproduced here in total.

"1. On 23 Jan 76, I flew aircraft 2423 as Crew Commander. The mission was an instrument proficiency flight and we were also to trial and give our appreciation of the PVHD. During the 1.6 hours of the flight flown at night we spent approximately 15 minutes doing the following trial:

- a. The aircraft was flown to seaward from Shearwater at 1000'. The weather was 3000 feet overcast and there was no natural horizon. There were no lights visible for visual cues through an arc of approximately 180° . The pilot's attitude indicator was failed and the cockpit lighting on the pilot's instrument panel was turned off. The co-pilot's attitude indicator and instrument lighting was left on and he monitored my flying to ensure that the aircraft remained in a safe flight envelope. With the aircraft's stabilization system engaged, altitude hold disengaged, and the light bar shining on the pilot's instrument panel I commenced rate one turns through 180° arc in both directions. I looked out the pilot's windshield constantly picking up the light bar reference in my peripheral vision. I performed eight 180° turns gradually increasing the angle of bank to approximately 25° . Feeling comfortable flying in this manner I decided to attempt some turns with the stabilization system disengaged. I successfully completed four 180° A.S.E. off turns using approximately 25° of bank. Ninety knots airspeed was maintained plus or minus five to ten knots during these turns. Again, the turns were executed by maintaining eyes "out of the cockpit" using peripheral vision only to note approximate angles and changes of the light bar vertically and rotationally.

2. Under the same conditions without the light bar these turns would have been impossible. During the 15 minutes of flying without the altitude hold engaged and with no indication of aircraft vertical speed, the aircraft was gradually climbed from 1000 to 2000 feet."

The report concludes "... the (Malcolm Horizon) may actually improve the accuracy of instrument flying; however, this could not be accurately assessed. It would seem reasonable to conclude though, that since the peripheral display has such an impact on heads-up flying, that it would also have a similar effect on instrument flying in that changes in aircraft attitude are immediately perceived by the pilot even though he may not be watching the attitude indicator; and the (Malcolm Horizon) would appear to have a valuable application for helicopter night operations requiring transitions to or concentration on visual references in instrument flying conditions. This type of flying is encountered during night approaches to ships at sea, helicopter night formation flying, helicopter tactical approaches to darkened areas etc."

In summary, all of the pilots who have flown the device reacted positively and would welcome the addition of the device to the cockpit.

Manufacture

A number of avionics manufacturing companies are currently putting together proposals for the licensing of the manufacture of the Malcolm Horizon. It is expected that such a license will be granted prior to this conference, and that the device will be available as a "shelf" item by late 1978.

Reference

Malcolm R., Money K.E., and Anderson P.J. Peripheral Artificial Horizon Display. AGARD Conference Proceedings No. 145 on Vibration and Combined Stresses in Advanced Systems, pp B20-1 to B20-3, 1975.

DCIEM Report 76-X-49

GROUND-REFERENCED VISUAL ORIENTATION WITH IMAGING DISPLAYS:
MONOCULAR VERSUS BINOCULAR ACCOMMODATION
AND JUDGMENTS OF RELATIVE SIZE

by

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SUMMARY

The application of dynamic sensor-generated imagery (SGI) and computer-generated imagery (CGI) analogous to a real-time contact view from an airplane calls for renewed investigation of the essential visual cues for contact flight. SGI and CGI systems have application both as contact analog flight displays and as outside visual scenes for flight simulators. In either case, systematic errors in distance judgments are encountered with all optical and electronic imaging systems, thereby requiring compensation by magnifying their images. Results of many psychophysical experiments partially account for but do not explain these bias errors in size and distance judgments.

During the past several centuries, countless experiments have been conducted to quantify the effects of reducing the cues to distance present in the peripheral visual field upon judgments of the size and distance of objects viewed foveally. Recently a few experiments have dealt with the influence of the peripheral visual surround upon visual accommodation, but no experiment to date has systematically related these three dependent variables: apparent size, apparent distance, and visual accommodation. Furthermore, textbooks in psychology, physiology, and physiological optics consistently dispense with visual accommodation as having no functional relation to size and distance judgments for objects beyond a few feet.

Despite the arbitrary discounting of accommodation as a mediating mechanism in the perception of size and distance, the experimental literature is replete with evidence to the contrary. To test the hypothesis that visual accommodation, possibly by attenuating the size of the retinal image projected by the crystalline lens, is a principal neuro-optical reflex mechanism mediating size-distance perception, a program of research is in progress at the Ames Research Center, NASA. Monocular and binocular judgments of size and distance of objects presented by various imaging media are being correlated with dynamic measurements of visual accommodation, using an infrared optometer, as a function of the textural distribution of the visual surround.

Results of the initial experiment support the following conclusions:

1. Accommodation to three-degree discs viewed binocularly at distances beyond the resting accommodation distance of about one meter shifts reliably nearer, and the discs appear smaller, when one eye is closed or covered; the magnitude of these shifts increases with distance.
2. There is a systematic shift in accommodation toward the resting position from either direction when one eye is occluded, but the systematic relationship between shifts in accommodation and shifts in perceived size were evident only at distances beyond the resting position, suggesting a dual process.
3. Shifts between binocular and monocular accommodation and perceived size are also affected interactively by the type of foveal target (plain or fancy) and by the presence or absence of a horizontal textural gradient in the lower half of the peripheral visual field.

BACKGROUND

Computer-generated flight displays are on the threshold of widespread use in presenting dynamic pictorial images analogous to the pilot's contact view, initially in visual systems for flight simulators and soon thereafter in airborne cockpit displays. Advocates of computer-generated imaging displays have assumed that all information essential to the pilot for ground-referenced maneuvers such as takeoff and landing is available from a clear view of the outside world. A great deal of effort on these "contact analog" displays is being directed toward generating realistic dynamic images of airports and their surrounding terrain and topography.

Determination of essential graphic characteristics in the generation of visual analogs of the outside world requires, at the outset, a renewed investigation of a paradox of visual perception. All computer-generated, sensor-generated, and optically generated displays that present synthetic images of the outside world have a common characteristic: they produce systematic errors in size and distance judgments. Bias errors in depth discrimination have been discovered independently by investigators working with

submarine periscopes, tank periscopes, aircraft periscopes, laboratory microscopes, "one-power" scopes for shotguns, and helmet-mounted CRT displays in addition to computer-generated imaging systems.

In each of these cases, the optical systems must be compensated by providing a magnification ranging between 1.2 and 1.5 to cause objects viewed through the optical system to appear at their objectively correct distances. The precise correction for each type of synthetic forward-looking imaging system has to be determined one by one. Although the correction needed for any given system, and in fact for each individual using a system, can readily be established empirically by a simple psychophysical experiment, determination of the causes of the constant perceptual errors presents an elusive problem as does the identification and quantification of the independent variables that affect their magnitude.

With one periscope that allowed variation of image magnification through the range of 0.8 to 2.0, Roscoe (1950) found that a magnification factor of 1.29 yielded subjective equality of distance judgments when compared with a direct view of a large elm tree across an open field adjacent to the laboratory. In flight, Roscoe, Hasler, and Dougherty (1966) found no tendency either to undershoot or overshoot on landings made with an image magnification of 1.20, but pilots systematically overshoot when landing with a minified image of 0.86 and undershot with an image magnified to 2.00. A magnification factor of about 1.25 appeared to be near optimum.

Campbell, McEachern, and Marg (1955) used a binocular periscope in a B-17 to study pilot performance in approach and landing. Unlike the previous studies, in which the image was projected onto a viewing screen, the outside world, in this case, was viewed directly through the lenses as with conventional binoculars. Again, to make the apparent distance of objects appear normal, a magnification of about 1.25 was required. Using an optical periscope with magnification set at unity, young pilots have a strong tendency to overshoot, although they normally can compensate for this tendency with practice.

The problem of biased distance judgments experienced by pilots flying airplanes with periscopes is shared by operators using helmet-mounted displays, by controllers of remotely piloted vehicles (RPVs), and by pilots flying simulators with optically or computer-generated pictorial landing displays. As stated previously, the proper correction can be determined empirically in each case, but a complete understanding of the variables contributing to the effect and the magnitudes of their individual influences would allow general rules rather than specific tests to guide the engineer in designing systems. Furthermore, such understanding would provide a basis for formulating testable theories of the visual perception of size and distance.

The literature of vision research is replete with unexplained experimental findings and assorted "optical illusions" that might be explained if it were shown quantitatively that the retinal angle subtended by an object is attenuated systematically as a function of the distance to which the eye is accommodated. There is now ample evidence that the relaxed, resting accommodation distance of the eye is not at optical infinity, as long believed and taught, but rather at about arm's length for most people, though varying widely among individuals (Malmstrom and Randle, 1976; Leibowitz and Owens 1975). Furthermore, the eye is lazy, and the complex reflexive adjustments that together comprise "accommodation" drive the accommodation level away from the resting position no more than is needed for the required discrimination.

Investigators of the accommodation process are repeatedly surprised at the fuzziness of the retinal image that the brain will accept uncritically as "good enough" if no fine discrimination is required. A partial explanation of bias errors in periscopic distance judgments and in judgments of the distance of objects presented on TV screens or viewed directly through frames, artificial pupils, vision reducing tubes, lenses, or prisms, as well as the shrinkage in the projection of after images through a telescope, may depend upon the fact that the eye accommodates to a distance other than that of the object being viewed.

The speculation just offered requires experimental verification or refutation, but meanwhile consider available evidence in its support. In viewing images projected by forward-looking infrared scanners, television, or periscopes onto a nearby screen, the eyes converge and accommodate to the distance of the screen, while objects presented thereon may appear to be at greater distances. The interposition of the screen provides binocular cues to the distance of the screen, including those associated with the muscular control of the converged eyeballs, but eliminates all binocular cues to the distance of individual objects imaged on the screen.

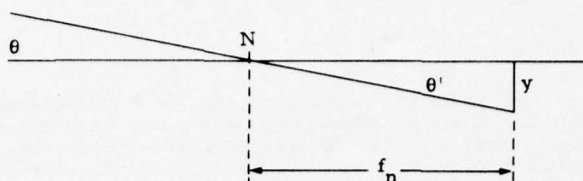
But, the increased curvature of the crystalline lens associated with near-field accommodation projects an image of an object onto the retina that subtends an angle smaller than that subtended by the same object projected through the lens when accommodated to optical infinity (Duke-Elder, 1936; Kilpatrick and Ittelson, 1953; Neumueller, 1948). Furthermore, the mechanism of accommodation involves several adjustments, including the stretching of the retina (Enoch, 1975), that would serve to increase the bias error. Thus, if the image of an object that is projected onto the retina covers a smaller portion of the retina than the image that would be projected if the eye were accommodated to the actual distance of the object, the object will appear to be at a greater distance than it actually is.

When accommodation increases, the anterior surface of the crystalline lens bulges in a forward direction with a corresponding decrease in its radius of curvature for this surface. It is generally accepted that this physical change in the eye's dioptric system serves primarily to increase its power so as to maintain optical conjugacy of the retina in image space and an object which approaches the eye in object space.

The nodal points of the schematic eye are used as the referent axial points in the computation of the size of the retinal image. Any ray from the object that is directed to the first of these points will emerge

from the system as if from the second point, and both rays will make the same angle of inclination to the optic axis (Ogle, 1961, p. 154). Since the distance between both the principal planes and the nodal planes is only about 0.3 mm, they may be considered coincident for most calculations, so only a single, intermediate point for each need be used.

For calculations of the retinal image size, the following construct is used:



N = nodal point

y = retinal image linear size

θ = object angular size

θ' = image angular size

N is point of unit angular magnification, so: $\theta' = \theta$.

$$\tan \theta' = y/f_n$$

$$\tan \theta = y/f_n, \text{ and for small angles,}$$

$$\theta = y/f_n \text{ radians}$$

The distance, f_n , will vary inversely with accommodation and directly with the radius of curvature of the anterior lens surface. This change is illustrated by two depictions of the Gullstrand simplified schematic eye by Bennett and Francis (in Davson, 1962, p. 104). They first show the optical constants for the eye accommodated to infinity (zero diopter) where f_n is taken equal to f_n' , the vertex focal length, 16.97 mm. The retinal image size of, say, the moon, which subtends about 30 minutes of arc at the earth's surface, is thus:

$$\theta = \frac{y}{f_n}$$

$$\frac{0.5^\circ}{57.3} = \frac{y}{16.97}$$

$$y = 0.148 \text{ mm}$$

However, the same visual angle, with 8.62 diopters of accommodation, would be smaller, and f_n would now be 14.825 ($f_n = 21.61 - N$, $N = 6.62 + 6.95/2$).

$$\theta = \frac{y}{14.825}$$

$$\frac{0.5^\circ}{57.3} = \frac{y}{14.825}$$

$$y = 0.129$$

The overall reduction in size of the retinal image for 8.62 diopters of accommodation is:

$$0.148 M = 0.129 \quad M = \text{Magnification}$$

$$M = \frac{0.129}{0.148}$$

$$M = 0.8716 \quad \text{about 13\% minification}$$

Thus, to restore the retinal image to the size it would be if the eye were accommodated to zero diopter would require a magnification of about 1.15 ($0.148/0.129$). A further magnification would be required to compensate for whatever stretching of the retina is involved.

Such an explanation might account for a major portion of the necessary magnification of images projected onto a cockpit CRT or periscope screen, but a similar, though smaller compensation is required when objects are viewed through lenses that collimate the incoming rays (Palmer and Pettitt, 1976). For our hypothetical explanation to hold in the general sense, it would be predicted that the lens of the eye shifts its accommodation toward the near field even though viewing an image collimated to optical infinity.

Recently, Hennessy and Leibowitz (1971) investigated the problem of "scope viewing errors" by measuring the dependence of visual accommodation upon the distance to the peripheral stimulus field surrounding a foveal fixation object presented at greater distances. Their results are interpreted as the initial experimental demonstration that the accommodation reflex is attenuated, though not determined completely, by peripheral as opposed to foveal stimulation. But, as in all previous studies, the relationship between accommodation and judgments of size and distance for objects presented foveally was not investigated.

PROBLEM

Surprisingly no reports can be found of experiments in which the dynamic accommodation of the eye has been measured while subjects were engaged in making size or distance judgments of objects at varying distances in varying backgrounds. Recent developments of research optometers and visual stimulators having this capability allow such experiments to be made with relative ease (Cornsweet and Crane, 1970; Randle, 1971). The experiment reported here is preliminary to a systematic, parametric investigation of the functional relationships between the perceived size and distance of objects and the accommodation of the eye in response to varying distributions of texture in the visual field.

Ultimately, experimentation will be required to determine the major effects of, and interactions among, a large number of stimulus variables embodied in a variety of visual environments in which unexplained visual phenomena are known to exist. Some of the phenomena are classified as optical illusions, such as the moon illusion; others are accepted as normal perceptions, but all remain inadequately explained. An adequate theory of size-distance perception, in addition to explaining bias errors in periscopic distance judgments, must account for all experimental facts associated with judgments of the size and distance of objects, however they may be presented.

Of the countless experiments dealing with psychophysical size-distance judgments, the classical study by Holway and Boring (1941) is perhaps the most frequently cited. Holway and Boring quantified the influence of variations in the visual surround on size judgments. Illuminated discs were presented at various distances and varied in size to maintain a central visual angle of one degree. With a filled visual surround from the observer to the object, monocular judgments followed a virtually perfect law of size constancy. Binocular judgments increased linearly with increasing object size but overshot the mark, the more distant one-degree discs appearing reliably larger than life size.

Restriction of the monocular visual surround by use of a 1.8-mm artificial pupil positioned 4 mm from the surface of the cornea produced a departure from size constancy in the direction of angle constancy, and a further restriction by the introduction of a tunnel of black cloth between the observer and the stimulus, thereby eliminating all texture surrounding the target except for a slight "haze," produced judgments closely approaching a constant response to the one-degree angle subtended, as would be predicted if the eye maintained a constant empty field myopia of one diopter in the absence of distance cues.

The difference between monocular and binocular distance judgments might be explained if it were to be demonstrated that the distance to which the two eyes accommodate when one is closed or covered is a compromise between accommodation to the filled visual field of the open eye and the empty field of the closed eye. The present experiment, in which visual accommodation was measured automatically while subjects compared the apparent sizes of discs viewed monocularly and binocularly at various distances up to four meters (0.25 diopter), included a preliminary investigation of the influence of foveal and peripheral textural detail upon both accommodation and perceived size.

EXPERIMENT 1: BINOCULAR VERSUS MONOCULAR SIZE

Experimental Variables

Subjects compared the perceived sizes of three-degree target discs presented at six distances when each was viewed monocularly and binocularly. Six discs, one for each of the six distances, were painted a flat white to provide relatively untextured "plain" targets, and a corresponding set of six discs with alternating quadrants of black and white were "fancy" targets, with distinct central focal points. Targets were extended toward the subject from a flat-black ring stand which could be positioned along a track, placed on a table, with stopping points at 0.25, 0.5, 1.0, 1.5, 2.0, and 4.0 meters (corresponding to accommodation stimuli of 4, 2, 1, 0.67, 0.50, and 0.25 diopters). The track also insured that the subject's left eye when positioned accurately (by the use of a hard wax "bite board" unique to each subject) and fixated on the target, would be aligned with the optical axis of the Cornsweet-Crane (1970) objective optometer with which the subject's accommodation was measured continuously. The optometer output was recorded on a Brush recorder and was simultaneously interfaced with a PDP-12 digital computer for direct data acquisition.

In addition to the type of target and the distance variables, illumination was manipulated in the following manner to provide either the presence or the absence of a textured intervening field:

In the "High" ambient illumination condition, the discs were presented immediately above a horizontal black and white checkerboard plane. When in place, the plane extended from just beyond the subject's chin to a distance of 4.5 meters, where a flat-white vertical curtain was placed. The plane, about a meter in width, was split lengthwise to allow the ring stand to slide along its track. Ambient illumination was provided by a diffuse DC lamp placed behind and above the subject. This illuminated the laboratory, giving an even distribution of light on the textured field and a brightness level of 0.20 ± 0.05 ftL on each target, as measured by a Pritchard photometer.

In the "Low" illumination condition, the horizontal textural gradient was eliminated by replacing the checkerboard plane with a black cloth, draping the background wall in black cloth, darkening the laboratory, and light-adapting subjects between trials. Targets were illuminated by a diffused flashlight beam, placed so that no visual surround was visible and so that each target reflected a brightness level equal to the High ambient illumination condition.

The order of presentation for combinations of targets and illumination conditions was counterbalanced across subjects. Each subject viewed targets at each of the six distances under one condition before progressing to the next condition. In each of the conditions targets were presented in both ascending (near to far) and descending (far to near) distance series. Half of the subjects viewed all four target/illumination combinations with the ascending series first; the conditions were then repeated for each subject and viewed with the descending series. The remaining subjects viewed the four conditions in descending order first, then in the ascending order.

Subjects

The subjects were 16 college students between ages 18 and 24. Prior to the experimental session, it was determined that all subjects exhibited 20/20 vision or better. Subjects were also screened for pupil size, since a small pupillary diameter produced unreliable accommodation measurements. Subjects were paid for their participation in the experiment, which lasted about four hours for each subject.

Procedure

Resting Position. The Crane and Cornsweet (1970) focus stimulator was used to determine each subject's resting accommodation distance. A black "X" target subtending approximately 3° was presented monocularly to the subject's left eye and was focused at 0 diopter; the right eye was occluded with an eye patch. After an initial 10-sec stabilization period, a 0.3-mm diameter pupil was automatically dropped into the optical system so that it was imaged at the entrance plane of the subject's eye. Illumination was simultaneously increased to maintain the initial brightness level. The artificial pupil increased the depth of field so that the target was always in focus; this situation was referred to as the "open loop" mode. Open loop accommodation was recorded for 120 sec. An identical procedure was repeated after initial focus on a 4 diopter target.

Size Comparisons. The "X" target and the focus stimulator were removed from the field of view, and subjects were told they were to make size comparisons between monocular and binocular views of discs under a variety of conditions. In their instructions, the subjects were informed that the purpose of the experiment was to determine whether or not the use of the monocular infrared optometer would induce shifts in apparent size, in either direction, between monocular and binocular views.

An index card, cut to fit around the nose, was used to occlude the right eye during monocular viewing. A dichroic mirror on the optometer, through which the subject looked with the left eye, caused targets to appear slightly blue-green while diminishing their apparent brightness. To keep the illumination level similar between the two eyes, a blue-green glass filter, cut in the same shape and size as the dichroic mirror, was mounted in front of the right eye and adjusted for each subject's interocular distance.

Subjects viewed each disc for 20 sec, beginning with either monocular or binocular vision and switching to the opposite view when the experimenter said "change" after 10 sec. Half of the subjects viewed targets binocularly for the first 10 sec of the first trial, while the remaining half started with the monocular view. After the first trial, starting conditions for subsequent trials were simply alternated

for each subject. Accommodation was continuously recorded during each 20 sec trial, after which the subject verbally reported whether the disc looked larger or smaller with one eye or with both. A forced-choice procedure was employed; subjects were not allowed to report that they saw no difference between binocular and monocular vision. This procedure was repeated for each of the 48 trials.

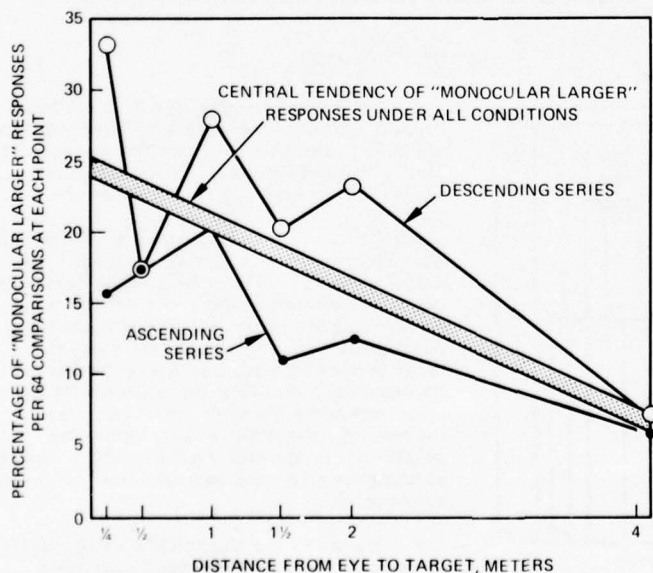


FIGURE 1. PERCENTAGE OF "MONOCULAR LARGER" RESPONSES IN JUDGMENTS OF THE RELATIVE SIZES OF DISCS VIEWED MONOCULARLY AND BINOCULARLY AS A FUNCTION OF VIEWING DISTANCE UNDER ALL CONDITIONS (PLAIN AND FANCY TARGETS, HIGH AND LOW ILLUMINATION)

Results

Size Judgments. In predictable agreement with previous findings, as targets were positioned at the maximum distance tested (4.0 m), the proportion of "monocular smaller" judgments approached unity, whereas at the shorter distances the disparity, while still evident, was less pronounced. The exceptions to the "monocular smaller" rule, namely the "monocular larger" judgments, are graphed in Figure 1, which also shows the hysteresis typical of all psychophysical data collected in ascending and descending series. Analysis of the variance of the responses, summarized and annotated in Table I, showed the ratio of monocular larger (ML) responses to decrease reliably with increasing distance ($p < 0.01$).

Although the other experimental variables accounted for relatively little of the

TABLE I. SUMMARY OF THE ANALYSIS OF VARIANCE OF ML RESPONSES

Legend: cell means = proportion ML responses			
Source of Variance	F	df	p
Series: Ascending and Descending	7.418	1	<0.02
Illumination: High and Low	4.919	1	<0.05
Targets: Plain and Fancy	1.615	1	=0.22
Distances: 0.25, 0.50, 1.0, 1.5, 2.0, 4.0 m	3.518	5	<0.01
<u>Cell Means and Main Effects</u>			
Series			
A = 0.138 D = 0.216	More ML responses were given in Descending series than in Ascending series.		
Illumination Level			
H = 0.201 L = 0.154	More ML responses were given when a horizontal textural gradient was visible than when there was none.		
Targets			
P = 0.195 F = 0.159	The frequency of ML responses to Plain targets was not reliably greater than it was to Fancy targets, but the interaction between Targets and Illumination Levels approached reliability ($p = 0.09$), the frequency of ML responses to Plain targets being about 50 percent greater when the textural gradient was visible, as did the interaction between Targets and Distances ($p = 0.08$), the ML responses to Plain targets being less frequent than to Fancy targets at 4 meters and more frequent at the shorter distances.		
Distances			
0.25 m = 0.242 0.50 m = 0.172 1.00 m = 0.242 1.50 m = 0.156 2.00 m = 0.180 4.00 m = 0.070	Multiple comparisons for repeated measures indicated that ML responses were reliably fewer at 4 m (0.25 D) than at any other distance and that no other pair differed reliably.		

response variance, reliable effects were present, as indicated and explained in Table I and graphed in Figure 2. The general pattern of these findings suggests that the tendency for foveally presented objects to appear smaller when viewed monocularly is influenced in a competitive manner by the peripheral as well as the foveal cues to distance and that the magnitude of these effects may be expected to increase rather than diminish as distances are increased beyond those tested.

Visual Accommodation. Inspection of the graphic records from the optometer revealed the typically oscillatory dioptric response of the eye with a rapid and generally accurate central tendency of response to targets presented at different distances. The central tendencies of responses during the first and second halves of the 10-sec intervals during which a given target was viewed either monocularly or binocularly were in close agreement, with the latter half being generally more stable. Consequently, the variances of the data for the second 5-sec interval following each target presentation were analyzed for the two extreme target distances of 1/4 meter and 4 meters, shown graphically in Figure 3.

The findings from the analysis are summarized and annotated in Table II. Because the vast preponderance of response variability is accounted for simply by target distance, the main effects and interactions of the other variables necessarily appear relatively small. Nevertheless, several are statistically reliable and meaningful despite wide variability of inter- and intra-individual responses. The annotations in Table II show clearly that, while the main effects of the experimental variables tend to balance across target distances, the reliable interactions among variables constitute the substantial findings from this experiment.

"MONOCULAR LARGER" RESPONSES
PER 192 COMPARISONS UNDER EACH CONDITION

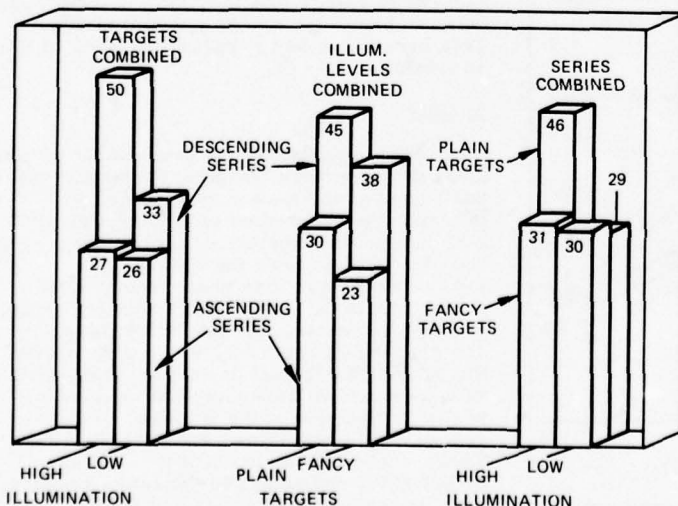


FIGURE 2. FREQUENCY OF "MONOCULAR LARGER" RESPONSES IN JUDGMENTS OF THE RELATIVE SIZES OF DISCS VIEWED MONOCULARLY AND BINOCULARLY AT DISTANCES RANGING FROM 0.25 TO 4.00 METERS UNDER THE CONDITIONS INDICATED

DISCUSSION

This experiment was a preliminary investigation of the relationships between visual accommodation and the perceived size of objects presented foveally at various distances up to four meters. Both perceived size and visual accommodation were found to vary systematically with shifts between binocular and monocular viewing: When one eye is closed or covered, accommodation to either near or far targets shifts toward the central, resting distance of about one meter; targets viewed with one eye only appear increasingly smaller than when viewed with both eyes as target distance is increased, the differences becoming relatively large and statistically reliable at distances beyond two meters for most observers.

Because the magnitude of the shifts in perceived size were not measured directly, the relative frequencies of "monocular larger" responses provide only an imprecise, inferential measure of shifts in perceived size. Furthermore, the traditional psychophysical procedure of presenting stimuli in

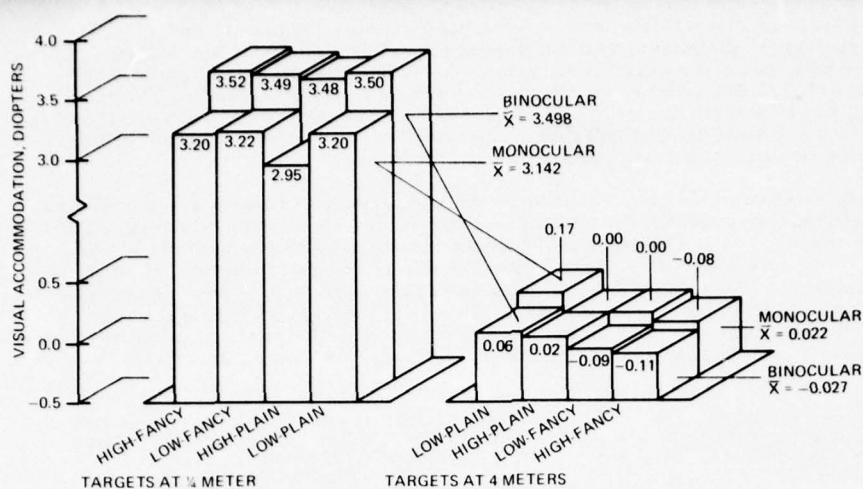


FIGURE 3. MEAN ACCOMMODATION LEVELS TO PLAIN AND FANCY TARGETS VIEWED AT 1/4 METER AND AT 4 METERS UNDER HIGH AND LOW ILLUMINATION

ascending and descending series elicited the well-known but not well-understood hysteresis effect that was not accounted for adequately by a corresponding hysteresis in accommodation. And finally, because of the many variables affecting inter- and intra-individual differences both in visual perception and in visual accommodation, 16 subjects are a precariously small sample for a psychophysical experiment. Despite these limitations, the results obtained support a number of scientific generalizations.

Both perceived size and visual accommodation are affected in coincidental ways by changes in both foveal and peripheral

stimulus texture. In the case of accommodation, three statistically reliable interactions, Illumination Levels \times Views ($p < 0.05$), Targets \times Distances ($p < 0.05$), and Views \times Distances ($p < 0.001$), were paralleled, respectively, by reliable shifts in perceived size with one eye or two for Illumination Levels ($p < 0.05$), a borderline interaction between Targets and Distances ($p = 0.08$), and Distances ($p < 0.01$). Furthermore, the three-way interaction, Targets \times Distances \times Views, that most closely corresponds to the two-way, Targets \times Distances, shifts in apparent size also closely approached reliability ($p = 0.055$).

TABLE II. SUMMARY OF ANALYSIS OF VARIANCE OF ACCOMMODATION DATA

Source of Variance	F	df	p
Series: Ascending and Descending	1.162	1	=0.298
Illumination: High and Low	0.861	1	=0.368
Targets: Plain and Fancy	0.439	1	=0.518
Distances: Near (1/4 m) and Far (4 m)	399.544	1	<0.001
Views: Monocular and Binocular	8.882	1	<0.01
<u>Reliable Interactions</u>			
Illumination x Views	5.710	1, 15	<0.05
Targets x Distances	5.095	1, 15	<0.05
Views x Distances	36.408	1, 15	<0.001
<u>Cell Means and Effects</u>			
<u>Series</u>			
A = 1.608 diopters D = 1.710	Mean accommodation levels for Ascending and Descending series did not differ reliably.		
<u>Illumination Levels</u>			
H = 1.624 L = 1.694	Accommodation level overall was not reliably affected by the illumination level.		
<u>Targets</u>			
P = 1.673 F = 1.644	Accommodation to Plain targets was not reliably nearer than to Fancy targets overall.		
<u>Distances</u>			
N = 3.320 F = -0.002	Accommodation to Near targets was reliably nearer than to Far targets		
<u>Views</u>			
M = 1.583 B = 1.735	Binocular accommodation was reliably nearer than Monocular overall.		
<u>Illumination x Views</u>			
H/M = 1.518 H/B = 1.729 L/M = 1.647 L/B = 1.741	Monocular accommodation was disproportionately nearer under Low illumination.		
<u>Targets x Distances</u>			
P/N = 3.282 P/F = 0.064 F/N = 3.357 F/F = -0.069	Fancy targets, whether near or far, attracted accommodation away from a central resting position.		
<u>Views x Distances</u>			
M/N = 3.142 M/F = 0.022 B/N = 3.497 B/F = -0.027	Monocular viewing drew accommodation outward from Near targets and inward from Far targets.		

As a further test of the nature of the reliable interactions between size judgments and accommodation levels at varying target distances, two contingent probability analyses were made. First, the relative frequencies with which the accommodation level shifted toward the mean resting accommodation for the subjects (1.133 diopters) were counted and tested as summarized in Table III. Shifts toward the mean resting position from the two nearest (1/4 and 1/2 meter) and the two farthest (2 and 4 meter) target positions were statistically reliable, indicating that the accommodation of the eyes is drawn toward the resting position when one eye is closed or covered.

The effects of the experimental variables are clouded by the wide range of resting accommodation positions (RPs) of different individuals, which in the present sample varied by a standard deviation of 1.020 diopters about a central tendency of 1.133 diopters, a mean resting position very close to one meter. To test the hypothesis that size judgments depend upon the direction and magnitude of shifts in accommodation between binocular and monocular viewing, relative to the individual's resting accommodation, a second contingent probability analysis was made. The joint probability that a shift in accommodation in the predicted direction will, by chance, be coincident with the corresponding predicted judgment of "larger" or "smaller" is 0.25 (1/2 x 1/2). Table IV summarizes this analysis.

TABLE III. SUMMARY OF CONTINGENT PROBABILITY ANALYSIS OF SHIFTS IN ACCOMMODATION TOWARD THE MEAN RESTING POSITION (1.133 DIOPTERS) WHEN ONE EYE WAS COVERED

Shift	Distance to Target, Meters					
	1/4	1/2	1	1-1/2	2	4
Toward RP	100	87	55	71	79	79
From RP	28	41	73	57	49	49
Chi ²	39.38	15.82	—	—	6.57	6.57
p	<0.001	<0.002	n.r.	n.r.	<0.05	<0.05

TABLE IV. SUMMARY OF CONTINGENT PROBABILITY ANALYSIS OF PREDICTED JUDGMENTS OF RELATIVE SIZE WITH CORRESPONDING SHIFTS IN ACCOMMODATION

Predicted Contingency	Distance to Target, Meters					
	1/4	1/2	1	1-1/2	2	4
Supported	28	15	29	46	49	57
Not supported	100	113	99	82	79	71
Percent support	22	12	23	36	38	45
Chi ²		11.34		7.59	11.34	25.01
p	n.r.	<0.002	n.r.	<0.01	<0.002	<0.001

Occurrence of the predicted contingency exceeded chance expectancy (25 percent) in a systematic way at target distances beyond one meter. Although the predicted contingency occurred less frequently than chance for targets at 1/2 meter, no systematic effect was evident at the three shorter target distances, where other cues such as the convergence of the eyes and binocular disparity become overpowering. Contrary to general belief, the correlation between relative size judgments and corresponding shifts in visual accommodation increases with distance. Recognizing that correlation does not guarantee a cause and effect relationship, this finding calls for an extended investigation of the functional relationships among distance and size judgments, visual accommodation, and the textural distribution of the visual field at distances beyond the 4-meter limit of this experiment.

REFERENCES

- Campbell, C. J., McEachern, L. J., and Marg, E. Flight by periscope. Wright-Patterson AFB: WADC TR 55-142, 1955.
- Cornsweet, T. N. and Crane, H. D. Servo-controlled infrared optometer. Journal of the Optical Society of America, 1970, 60, 548-554.
- Davson, H. The eye, Volume 4. New York: Academic Press, 1962.
- Duke-Elder, W. S. Textbook of ophthalmology. St. Louis: Mosby, 1936.
- Enoch, J. M. Marked accommodation, retinal stretch, monocular space perception and retinal receptor orientation. American Journal of Optometry and Physiological Optics, 1975, 52, 376-392.
- Hennessy, R. T. and Leibowitz, H. W. The effect of a peripheral stimulus on accommodation. Perception and Psychophysics, 1971, 10, 129-132.
- Holway, A. H. and Boring, E. G. Determinants of apparent visual size with distance variant. American Journal of Psychology, 1941, 54, 21-37.
- Kilpatrick, F. P. and Ittelson, W. H. The size-distance invariance hypothesis. Psychological Review, 1953, 60, 223-231.
- Leibowitz, H. W. and Owens, D. A. Anomalous myopias and the intermediate dark focus of accommodation. Science, 1976, 189, 646-648.
- Malmstrom, F. V. and Randle, R. J. Effects of visual imagery on the accommodation response. Perception and Psychophysics, 1976, 19, 450-453.
- Neumueller, J. The correction lens. American Journal of Ophthalmology, 1948, 25, 247-261.
- Ogle, K. N. Optics. Springfield, Ill.: Charles C. Thomas, 1961.
- Palmer, E. and Petitt, J. Visual space perception on a computer graphics night visual attachment. Proceedings of the AIAA visual and motion simulation conference. New York: Institute of Aeronautics and Astronautics, 1976.

- Randle, R. J. Volitional control of visual accommodation. Proceedings of the AGARD conference on adaptation and acclimatisation in aerospace medicine. Neuilly-sur-Seine, France: North Atlantic Treaty Organization, 1971.
- Roscoe, S. N. Aircraft pilot performance as a function of the extent and magnification of the visible horizon. Unpublished doctoral dissertation, University of Illinois at Urbana-Champaign, 1950.
- Roscoe, S. N., Dougherty, D. J., and Hasler, S. G. Flight by periscope: Making takeoffs and landings; the influence of image magnification, practice, and various conditions of flight. Human Factors, 1966, 8, 13-40. (Originally issued in 1952 by the Office of Naval Research as Human Engineering Report SDC 71-16-9.)

TERRAIN FOLLOWING USING STEREO TELEVISION

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SUMMARY

An experiment was conducted to determine whether low-altitude, terrain-following flight could be accomplished better with stereo television than with conventional two-dimensional television. Nine subjects, both pilots and nonpilots, flew a simulated F-4 aircraft using only the information supplied by an air-to-ground television system. The simulation system consisted of 12-by 30-foot, 2,000:1 scale terrain model, a gantry system carrying the television camera, a moving base cockpit, and associated computer hardware that provided the proper control stick responses.

The subject's task was to fly as low as possible across a 9-mile flight corridor without going below 250 feet above ground level. A single path that varied from sea level to 4,000 feet and at a constant airspeed of 300 knots was flown by all subjects. The subjects could control only the vertical dimension of the aircraft's flight.

Independent variables in the experiment were three television camera downlook angles (6, 8, and 10 degrees) and three television camera separations (none, 31, and 52 feet). Analyses of variance were performed on the data from the experiment for the following performance measures:

1. Number of penetrations below 250 feet
2. Average altitude above 250 feet
3. Average g on the pilot
4. Standard deviation of altitude
5. Standard deviation of g

The following conclusions were reached:

1. Stereo television was significantly better than conventional television for minimizing the number of undesired excursions below 250 feet. The 52-foot simulated camera separation was significantly better than the 31-foot camera separation.
2. The nine subjects who participated in the experiment were a greater source of variability in all five analyses of variance than any other factor. No effects other than subjects were significant for minimizing average altitude above the terrain.
3. Television camera separations had a statistically significant effect upon average g-loading on the subjects. Average g-loading was lowest with the 52-foot separation and highest with conventional television.
4. Both pilots and nonpilots are able to remotely control an airborne vehicle using only a continuous video picture of the ground when vehicle parameters other than pitch and altitude are automatically controlled.

INTRODUCTION

The increasing effectiveness of sensing systems and data processing systems that are able to present large amounts of data have taxed the operator beyond his ability to assimilate the data through traditional display techniques. Man possesses a highly refined sense of depth that is not used when viewing conventional two-dimensional displays. If depth were added to the display, one should obtain both increased system capacity and increased operator efficiency by taking advantage of a previously unused capability. The perception of distance and depth plays an important part in low-level flight and becomes vital in the judgment of terrain contours during low-altitude, high-speed flight and during helicopter landing area selection.

Gold (1972)¹ has shown that a major cue to depth perception is retinal disparity. The separation between the eyes (about 2 1/2 inches) means that each eye receives a slightly different view of an object. This difference enables an individual with good depth perception (10 seconds of arc) to resolve a 10-foot difference between objects at a distance of 210 feet. If some method were available for expanding this interocular separation, theoretically, greatly improved depth perception would result.

This principle was recognized prior to World War II. Before the advent of radar, antiaircraft guns were visually directed. Many of the sighting systems incorporated an expanded base stereoscopic viewing system. These telestereo viewing systems were forgotten when radar-directed antiaircraft fire-control systems became common.

An adaptation of the same principle followed with the early antiaircraft gunsights, would be to mount one television camera on each wing of an aircraft. Video from the left- and right-wing cameras could be transmitted to the corresponding eyes of the observer with the use of either two

¹Gold, T. "The Limits of Stereopsis as a Cue for Depth Perception in Dynamic Visual Situations," in Society for Information Display 1972 Digest of Technical Papers. Pp. 150-151.

displays or a single split-screen polarized display. Except for television system resolution losses, the result should be that the observer would see depth as he would if he were a giant with wide-set eyes. Thus, if a 2 1/2-inch interocular separation allows an individual to resolve a 10-foot depth difference at 210 feet, a 25-foot separation (120 times 2 1/2 inches) should enable an observer to resolve a 10-foot depth difference out to 25,200 feet (120 times 210). Graham (1965)² has claimed that some depth information is available from retinal disparity out to a distance of about 1,500 feet. Consequently, a 25-foot separation should provide some depth cues out to 180,000 feet. Even if television system resolution losses cut these figures substantially, an improvement in depth perception would have operational utility.

Because the potential benefits to the airborne operator of stereo television appeared large, work was initiated in this area. It was first verified that the concept of stereo television would work by taking two television cameras to the roof of a three-story building. Stereo television was found to be technically feasible, and it was observed that some scene magnification is needed to resolve small details in depth at longer ranges.

STEREO TELEVISION SIMULATION SYSTEM

It was decided that the best way to answer the design questions associated with the development of stereo television would be to begin a program of simulation research with the use of a terrain model and a gantry carrying the television cameras. A prototype stereo television probe that simulated a 50-foot camera separation at a 2000:1 scale was constructed. The terrain image is rotated 90 degrees by a mirror at the base of the probe and is then scanned by a 25-millimeter focal-length objective lens of f/2.0 aperture with a 45-degree field of view. Behind the lens is an interchangeable metal tab containing dual apertures separated by either 3/16, 1/4, or 3/8 inch. At a 2000:1 scale, these apertures correspond to 31-, 42-, and 52-foot television camera separations. Smaller or larger separations can be simulated by changing the simulation system scaling. One of these apertures is polarized horizontally and the other is polarized vertically. When the tab is removed, a conventional two-dimensional television scene is generated. This assembly is held by a threaded mount that can be moved nearer or farther from the mirror to vary the depth of field.

Both images from the objective lens are divided into two channels by the beam splitter. Behind the beam splitter are two diagonally oriented mirrors that align the scene image with the center of the television vidicons. From these mirrors, the image passes through two polarizing filters. The direction of polarization on these filters is the same as that on the corresponding objective lens tab aperture. Consequently, the right-hand camera sees only what passes through the right-hand objective lens tab aperture and the left-hand camera sees only what passes through the left-hand objective lens tab aperture. Behind the polarizing filters, each channel contains a one-half power magnification relay lens that reimages the scene onto the television camera vidicon. The field of view at the television camera vidicon is 30 degrees horizontally and 22 degrees vertically. The cameras used are two high-resolution, 20-megahertz, COHU series 2000, black and white television cameras. Scan line patterns from 525 to 955 lines can be generated.

In addition to generating a stereoscopic television image, the stereo probe also simulates aircraft or missile roll, pitch, and yaw. Roll is provided by rotating the outer mount assembly to which both cameras are attached; pitch is provided by rotating the probe mirror about its axis; and yaw is provided by rotating the cameras individually within the mount assembly.

Video from the television cameras is displayed to the operator by the use of a dual monitor viewing system. It consists of two 15-megahertz, CONRAC, 8-inch (diagonal measure) television monitors and two mirrors mounted on a movable slide. Figure 1 is an overhead sketch of the viewing system.

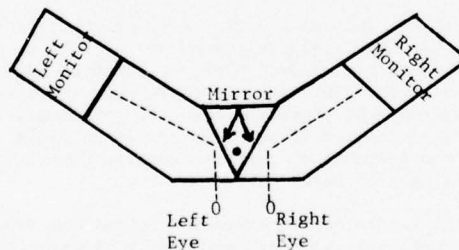


Figure 1. Stereo Television Viewing System

To see stereo television, the observer must be positioned so that each eye sees only the image in one mirror. The mirrors are adjustable fore and aft from the observer, which in turn moves the images closer together or farther apart. This system allows each observer to optimally adjust the television display scene to match his interocular separation. The mirror system reverses the right and left sides of the display scene, but the scene appears correctly because a similar scene reversal was built into the optical probe. Although the stereo television viewer used in the study is quite bulky, it should be possible to incorporate the same principles into a helmet-mounted television system suitable for aircraft use. The design characteristics of the stereoscopic television system just described are summarized in table 1.

²Graham, C.H. Vision and Visual Perception, New York, Wiley & Sons, Inc., 1965. P. 525.

Table 1. Design Characteristics of Television and Optical Probe Systems

Television System			
System Features	Two COHU Series 2000 Cameras	Two CONRAC CNBS Monitors	
Bandwidth (megahertz)	20	15	
Line rates	525, 729, 873, 945	945	
Signal-to-noise ratio (decibels)	40	—	
Center horizontal resolution (lines)	800	650	
Center vertical resolution (lines)	650	600	
Grey scale (shades)	10	10	
Optical Probe			
Scale	Stereo Separations		
Actual (inches)	3/16	4/16	6/16
500:1 scale (feet)	7.8	10.4	13.0
1,000:1 scale (feet)	15.6	20.8	26.0
2,000:1 scale (feet)	31.3	41.7	52.1
Field of view:	30 degrees horizontal and 22 degrees vertical.		
Depth of view:	Adjustable from 1/4 inch to infinity.		
Stereo convergence point:	Adjustable from 18 inches through 96 inches.		
Flight Simulation Capability			
Motion	Range (Degrees)	Rate (Degrees per Second)	Acceleration (Degrees/Second/Second)
Roll	±360	300	650
Pitch	±45	60	100
Yaw	±360	25	100

Simulated aircraft flights with the stereoscopic television system are flown across a unique modular three-dimensional terrain model from which many different terrain configurations can be built. The basic terrain contains no features that relate to a specific scale size such as trees, roads, or buildings. Scale-model targets and other fixed scale features are added as desired. This design approach enables the simulation of scales from about 500:1 through 10,000:1. Flights across the terrain model are made by a gantry system carrying the television probe previously described. It is capable of longitudinal, lateral, and vertical motion. This movement capability combined with that available on the probe allows accurate simulation of the movements of a wide range of aircraft and missiles. Table 2 describes the terrain model and gantry system characteristics.

Table 2. Design Characteristics of Terrain Model and Gantry

Features	Actual	500:1 Scale	2,000:1 Scale	10,000:1 Scale
Terrain size	12 by 30 feet	1 by 2 1/2 nautical miles	4 by 10 nautical miles	20 by 50 nautical miles
Altitude	3/4 inch to 10 feet	31 to 5,000 feet	125 to 20,000 feet	625 to 100,000 feet
Forward speed	0 to 100 feet per minute	0 to 500 knots	0 to 2,000 knots	0 to 10,000 knots
Vertical speed	0 to 50 feet per minute	0 to 250 knots	0 to 1,000 knots	0 to 5,000 knots
Lateral speed	0 to 50 feet per minute	0 to 250 knots	0 to 1,000 knots	0 to 5,000 knots

Flights across the terrain model can be flown either from a static cockpit or from a dynamic flight simulator. Although it was originally designed as a helicopter simulator, during FY 1972 it was modified to simulate an F-4 aircraft. It is capable of limited motion in all six degrees of freedom. Within these limits, it can be programmed to fly like any fixed-wing aircraft or helicopter. An analog computer system provides aircraft equations of motion, and a control loading system provides inputs that result in flight-control characteristics similar to those present in "real" aircraft. This realism can be enhanced further by stimulus generators, which provide aircraft background noise, vibration, and cockpit temperature variations.

STEREO TELEVISION RESEARCH STUDY

A stereo television research program was initiated to determine:

1. What is the relationship between television camera separation and depth perception?
2. For what tasks does stereo television improve operator performance?
3. If significant operator task improvement results, can a prototype flight system be built and demonstrated?

Answers to the first two questions are being obtained through a program of flight-simulation research. Before an acceptable simulation research experiment could be designed, however, it was necessary to determine what constitutes good terrain-following flight performance and to devise a way of adequately measuring this performance in the laboratory. A review of the literature provided the answers to both problems. Pelton (1958),³ as reported in Ruby and Monty (1963),⁴ showed that for penetration against a HAWK-type defense, an aircraft must attain an average clearance altitude that is

³ Cornell Aeronautical Laboratory, Inc. Avoidance Concepts for Terrain Avoidance, by F. M. Pelton, Buffalo, N.Y., 1958. (Report No. IH-1224-P-4) SECRET

⁴ Cornell Aeronautical Laboratory, Inc. Human Tracking Ability for Maximum Terrain Following, by W. J. Ruby and R. A. Monty. Buffalo, N.Y., Aug 1963. (Report No. IH-1715-E-5, AD 431 116) UNCLASSIFIED.

less than the rms (root mean square) variations of the terrain profile along the ground track. His study also showed that flying a trajectory that attempted to match the profile of the terrain substantially increased the survivability of the aircraft against surface-to-air missiles compared with a profile that attained the same average clearance by reducing the vertical excursions about the mean flight altitude. In other words, to achieve the maximum protection afforded by terrain masking, it is necessary to fly as close as possible to the terrain at all times. However, as the altitude of the penetrating aircraft decreases, the attrition due to crashing increases. The ideal terrain-following altitude is that altitude at which total attrition is at a minimum.

TERRAIN-FOLLOWING EXPERIMENT

There are a number of possible measures of terrain-following flying performance. Ruby and Monty (1963)⁴ recommended normalized average clearance, whereas Williams (1969)⁵ uses rms altitude error, rms g-loading, and integrated absolute error without indicating a preference. Since computerized data analysis techniques simplify the effort required to conduct multiple analyses, all of the above measures were used. The use of multiple dependent variables should provide a better estimate of what constitutes good terrain-following performance than a single measure would, because it is possible to study the interactions among criteria. For example, flying a low profile that closely follows the hills and valleys requires more g-loading on the aircraft than does a more relaxed profile, but at the same time increasing the g's too much will either overstress the aircraft or increase the probability of crashing into the terrain.

It would be desirable from a simulation standpoint to allow the pilot to crash into the terrain. Unfortunately, this might damage the optical probe and would certainly damage the terrain. Therefore, an automatic collision avoidance system was added to the optical probe. It consisted of a wire below the mirror, which, when it contacted the terrain, activated a microswitch that rapidly elevated the probe 3 inches (500 feet at a 2000:1 scale). To avoid unpleasant surprises to the pilot, this signal was not fed to the dynamic motion platform. This system reduced the minimum flight altitude to 250 feet.

The pilot's altitude above the terrain was determined with a sonar system similar to the STAR system developed by North American Rockwell, Columbus, Ohio, for use with their terrain model. Our system was designed and constructed in-house. It consisted of a 200-kilohertz, transmitting and receiving, ultrasonic transducer attached to the optical probe. Signals from the transducer were amplified and converted to a format suitable for recording on magnetic tape and on a strip chart recorder. With this system, absolute altitude was measured within ± 25 feet up to altitudes of 2,000 feet above the terrain.

The pilot's task consisted of flying as low as possible across moderately rugged terrain without going below 250 feet above ground level (AGL). A single path across the terrain model was chosen for all flights. The flight length was 9 miles, and terrain altitude varied from sea level to 4,000 feet. A constant airspeed of 300 knots was used. Flight time varied depending on the amount of vertical aircraft movement. Aircraft altitude above the terrain was recorded every 500 feet of forward aircraft movement by a chain-driven cam on the longitudinal axis of the gantry. Recording altitude in this manner enabled altitude samples to be taken above the same points on every pass. Terrain modules that contained sustained changes in terrain altitude had a mean slope of 21 degrees. The actual contour of the terrain varied by as much as ± 200 feet from the mean slope on each terrain module.

The flights were flown from the dynamic flight simulator. Since most of the flight parameters were constant and not under the control of the pilot, only two degrees of freedom of motion were required: pitch and heave. These were programmed with F-4 aircraft equations of motion. Flight instruments were purposely excluded from the cockpit so that the only source of flight information was the television presentation. Independent variables in the experiment were:

Three television camera downlook angles:	6, 8, and 10 degrees
Three television camera separations:	0, 31, and 52 feet
Three television camera depth of fields:	3,000 to 6,000 feet; 3,500 to 9,000 feet; and 4,000 to 13,000 feet.

The simplest way to mount a television camera to an aircraft wing would be to mount it in a fixed position. If this is done, some camera downlook will be necessary to prevent the camera from seeing mostly sky when the aircraft is climbing a hill. Preliminary simulation flights convinced us that the optimum camera downlook from the horizontal was within the 6-to-10-degree range. Therefore, camera downlook angles were included as independent variables.

The 0-degree television camera separation used a single television display. Both 31-and 52-foot stereo separations were included to determine whether usable depth information increased linearly with increased camera separation. It is likely that it does not, especially in our simulation, because insufficient scene magnification is present to take advantage of the greater range of depth perception theoretically available.

Television camera depth of field in actual flight should be practically unlimited because the large quantity of light available will permit the use of a small f stop on the cameras. Depth of field was included as an independent variable to determine what distances ahead of the aircraft are most important in the terrain-following task.

⁵ Aerospace Medical Research Laboratory. Predictor Displays for Low-Altitude High-Speed Flight, by W. L. Williams. Wright-Patterson AFB, Ohio, AMRL, Feb 1969. (AMRL-TR-68-118, AD 857 276) UNCLASSIFIED.

Each subject flew 27 terrain-following flights in a single time period of about 2 hours. Every factorial combination of independent variables was flown once by each subject. The flights were grouped by downlook, and all flights within a downlook condition were flown before proceeding to the next downlook. This was done in order to avoid confusing the pilot concerning how far ahead of his aircraft he was looking. The downlook order for each subject was determined by a 3 x 3 Latin square; therefore, downlook presentation order was balanced for every group of three subjects. A 10-minute break was taken between downlooks. Three training flights were provided prior to each new downlook group of flights. Previous experience suggested that these trials were sufficient for performance to stabilize. During the training flights, subjects received feedback of their performance by a continuous verbal description through earphones of their altitude above the terrain.

Within each group of nine flights all possible combinations for three camera separations and three depth of fields were used once. Pairing sequences were partially counterbalanced for each subject and were completely counterbalanced for each group of three subjects. These procedures were followed to minimize sequence effects and unknown interactions.

Nine subjects were used in the experiment. Three of them were F-4 pilots, three were non-F-4 pilots, and three were nonpilots. All subjects except military pilots were tested for near and far visual acuity and for depth perception using the Bausch and Lomb Master Ortho-Rater. Subjects other than military pilots were required to have 20/20 near and far acuity in each eye and to be able to resolve a stereopsis angle of 9.7 minutes of arc. Qualified military pilots were assumed to have adequate acuity and depth perception. None of the subjects wore glasses or contact lenses.

RESULTS AND DISCUSSION

Five analyses of variance were performed on the data from the experiment:

1. Number of penetrations below 250 feet
2. Average altitude above 250 feet
3. Average g on the pilot
4. Standard deviation of altitude (2)
5. Standard deviation of g (3)

Each analysis partitioned the variance into components attributable to (1) subjects, (2) runs, (3) downlook, (4) focus, (5) separations, (6) downlook by focus interactions, (7) downlook by separations interactions, (8) focus by separations interactions, and (9) downlook by focus by separations interactions. Detailed descriptions of the statistical model, procedure, and results are contained in the appendix.

Table 3 summarizes the significant results of the five analyses of the data. Subject effects were significant for all of the analyses. Television camera separations were significant in the analyses of number of penetrations below 250 feet and average g on the pilot. Television camera downlooks were significant in the analyses of the standard deviations of average altitude above 250 feet and average g on the pilot. No other sources of variance including interactions were significant at $p < 0.05$.

Table 3. Summary of Analyses of Variance Results

Criterion	Results
1. Number of penetrations below 250 feet	Subjects $p < 0.005$ Separations $p < 0.05$
2. Average altitude above 250 feet	Subjects $p < 0.005$
3. Average g on the pilot	Subjects $p < 0.005$ Separations $p < 0.05$
4. Standard deviation of item 2	Subjects $p < 0.005$ Separations $p < 0.025$
5. Standard deviation of item 3	Subjects $p < 0.005$ Downlook $p < 0.005$

Subject averaged 20.5 low penetrations overall during the 27 flights comprising the experiment for each subject. With the exception of one subject (a non-F-4 military pilot) who had 42 penetrations below 250 feet, all other subjects had between 13 and 21 low penetrations.

Figure 2 presents a comparison of how well the individual subjects performed on correct altitude maintenance. The grand mean altitude maintained above the 250-foot minimum altitude was 252 feet, which is equal to 502 feet above the terrain. The standard deviation of the mean was 371 feet. Minimum average altitude error was 39 feet by subject five, and maximum average altitude error was 528 feet by subject nine. Considering the ruggedness of the terrain and the fact that no flight instrument information was available, subjects as a group consistently were able to fly remarkably close to the terrain. Their performance undoubtedly was aided by the fact that they needed to control only the vertical dimension of the simulated flights. Nevertheless, these results present encouraging evidence that piloted and remotely piloted vehicles (RPVs) can be flown close to a terrain using only visual information.

Figure 2 also indicates the extent to which subjects: (1) were good at both maintaining a low average altitude above the terrain; (2) were good at one task but not the other; or (3) were good at neither. A Pearson product-moment correlation was computed on the data in figure 2 and was found to be $r = 0.281$. This means there was a small tendency for individual subjects to perform similarly on both tasks.

Table 4 shows how the three subject groups (F-4 pilots, nonpilots, and non-F-4 pilots) compared in performance.

* Here g refers to the acceleration force through the vertical (Z) axis of the pilot, ie., g_z .

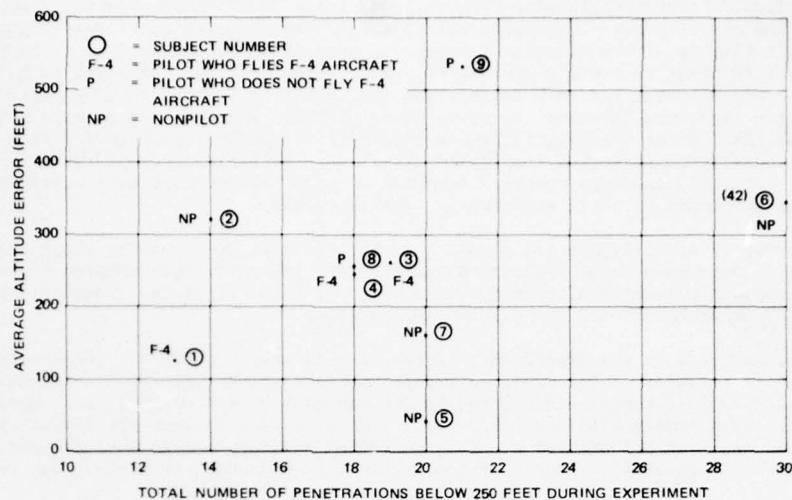


Figure 7. Average Altitude Error Versus Number of Penetrations Below 250 Feet.

Table 4. Average Altitude Error and Number of Penetrations Below 250 Feet for Subject Groups

Subject	Penetrations	Altitude Error (Feet)
F-4 pilots	16.6	210
Nonpilots	18	173
Non-F-4 pilots	27	377

Since the altitude control system was programmed to respond like an F-4 aircraft, these results are generally consistent with a transfer of training model that would anticipate positive transfer of training for the F-4 pilots and negative transfer of training for non-F-4 pilots. However, the subject groups are extremely small (three each); therefore, no generalizations are warranted to the population as a whole on this type of task.

The use of conventional versus stereo television had no significant effect on average altitude error. However, television camera separations were significant variable in determining the total number of low penetrations. A total of 71 low penetrations occurred with monoral television versus an average of 57 with stereo television. The 31-foot separations recorded 68 low penetrations, while the 52-foot separation recorded only 46 low penetrations.

The authors have no ready explanation why the 52-foot separation was so superior to the 31-foot separation. It is logical to assume that if performance were to improve using stereo television, the improvement should be true of both stereo separations, although somewhat better performance would be expected with the wider separation. One possible rationale for the results is that the simulation process optically degraded the 31-foot separation but not the 52-foot separation. This could have occurred if the polarization elements used to generate the 31-foot separation were inferior to either manufacture or installation to those used to generate the 52-foot separation.

Average g on the pilot during the experiment was 0.900, with a standard deviation of the mean of 0.371. The mean g 's on the pilot for various television camera separations are as follows:

Monoral = 0.906
 Stereo (31 feet) = 0.900
 Stereo (52 feet) = 0.895

While these differences are statistically significant, the magnitude of the differences is small and probably of small practical importance. Television camera downlook angle had no significant effect on any of the three performance measures, but it was significant in the analyses of standard deviations of both altitude above the terrain and average g on the pilot. Table 5 shows the effect of camera downlook on these standard deviations.

Table 5. Effect of Television Camera Downlook on the Standard Deviations

Downlook (Degrees)	Standard Deviation Altitude (Feet)	Standard Deviation of g
6	405	0.45
8	367	0.48
10	340	0.55

The increased size of the standard deviation of g -loading, as downlook increases, is probably

caused by the fact that steeper lookdown angles restrict the subject's ability to anticipate changes in terrain elevation by looking further ahead. Instead, the subject is forced to make more sudden corrections that result in a wider variance of g-loadings. At the same time, this flying behavior tends to keep him from overanticipating terrain changes. Too much anticipation of terrain elevation changes at a shallow downlook would result in a smoother flight path characterized by more sustained g-loadings. This path would tend to "scalp" the top of ridges and be high over valleys. Average altitude error and average g-loading over the same path could be similar using either technique, but the standard deviations would be as described. If the above assumptions are correct, flying with a shallower downlook would demand less attention and should be less fatiguing, but at a possible cost of greater vehicle exposure. Steeper camera downlook angles demand more continuous attention to the flying task but tend to prevent flying excessively high over valleys.

At the end of each subject's participation in the experiment, he was asked which downlook angle he liked best and least. One subject had no preferences. The preferences of the remaining eight subjects are contained in table 6.

Table 6. Subject Preference for Downlook Angles

Downlook (Degrees)	Liked Best	Liked Least
6	2	4
8	2	1
10	4	3

The 8-degree downlook caused the least polarization of opinion and is acceptable (not selected as liked least) to the largest number of subjects.

CONCLUSIONS

1. Stereo television was significantly better than conventional television for minimizing the number of undesired excursions below 250 feet. The 52-foot simulated camera separation was significantly better than the 31-foot camera separation. The 31-foot separation showed better performance than monoral television, but the difference is not statistically significant.
2. The nine subjects who participated in the experiment were a greater source of variability in all five analyses of variance than any other single factor. No effects other than attributable to subjects were significant for minimizing average altitude above the terrain.
3. Television camera separations had a statistically significant effect on average g-loading on the subjects. Average g-loading was lowest with the 52-foot separation and highest with monoral television. The magnitude of the difference was small (less than 2 percent).
4. Both pilots and nonpilots are able to remotely control an airborne vehicle using only a continuous video picture of the ground when vehicle parameters other than pitch and altitude are automatically controlled, although there were important differences in their performances.

RECOMMENDATIONS

The analysis of undesired flight excursions below 250 feet presents encouraging evidence that stereo television improved low-altitude flight performance. It is recommended that a prototype system be developed through a flight-test program that will have the following objectives:

1. Verify that operational problems such as television camera alignment and aircraft wingflex can be solved.
2. Explore additional applications for stereo television including target acquisition, remotely piloted vehicle takeoff and landing, and low-light-level use.
3. Determine optimum system characteristics for these tasks.
4. Obtain video tape recordings to document results and demonstrate system characteristics.

REFERENCES

1. Gold, T. "The Limits of Stereopsis as a Cue for Depth Perception in Dynamic Visual Situations," in Society for Information Display 1972 Digest of Technical Papers. PP. 150-151.
2. Graham, C. H. Vision and Visual Perception, New York, Wiley & Sons, Inc., 1965. P. 525.
3. Cornell Aeronautical Laboratory, Inc. Avoidance Concepts for Terrain Avoidance, by F. M. Pelton. Buffalo, N.Y., 1958. (Report No. IH-1224-P-4) SECRET.
4. Human Tracking Ability for Maximum Terrain Following, by W. J. Ruby and R. A. Monty. Buffalo, N.Y., Aug 1963. (Report No. IH-1715-E-5, AD 431 116) UNCLASSIFIED.
5. Aerospace Medical Research Laboratory. Predictor Displays for Low-Altitude High-Speed Flight, by W. L. Williams. Wright-Patterson AFB, Ohio, AMRL, Feb 1969. (AMRL-TR-68-118, AD 857 276) UNCLASSIFIED.
6. Dixon, W. J. ed. BMD Biomedical Computer Programs. Los Angeles, Calif., University of California Press, 1975.

APPENDIX

ANALYSIS SUMMARY FOR FIVE TERRAIN-FOLLOWING CRITERIA

This section contains a summary of the model procedures, and results of five analyses of the data from this experiment. Each analysis employed the same basic model and differed only in the criteria under analysis: (1) penetration below 250 feet, (2) average altitude above 250 feet, (3) average g on pilot, (4) standard deviation in altitude, and (5) standard deviation in g. For any particular criteria, the model for every observation (datum) consists of ten additive components that vary with conditions of observation and a grand average component common to all observations. Names for these components and their descriptions are:

Subject (S)	A component reflecting which of the nine subjects generated the score.
Run (R)	A component denoting during which of the 27 runs the observation was collected.
Downlook (D)	A component indicating which of the three downlooks was employed.
Focus (F)	A component denoting under which of the three focus conditions the observation was made.
Separation (S)	A component indicating which of the three separations was employed.
D * F	An interaction term particular to the downlook (D) and focus (F) combination employed.
D * S	A term reflecting the particular combination of downlook and separation under which the score was made.
F * S	An interaction term particular to the focus and separation combination employed.
F * D * S	An interaction term indicating the joint focus, separation, and display condition under which the observation was made.
Error	The difference between the observation and the sum of the additive components, i.e., a reflection of the variance not explained by the model.

Both the least squares fitting and the variance partitioning were accomplished by using a generalized multiple regression analysis computer program: BMD02R developed by Dixon (1965). As employed, this program falls under Overall and Spiegel's (1969) Method 1: "Complete Linear Model Analysis." It sequentially extracted the effects of various sources of variance and printed the amount of variance contributed by each term independently of all preceding terms.

The order that the terms were removed in the analysis was the same order that the terms were incorporated into the model, i.e., subjects, runs, downlook, focus, etc. Since the various components were designed to be orthogonal, the order of incorporation ordinarily would have no effect. Unfortunately, contrary to the design, there was a loss of four cases (out of 243 possible) for each of the analysis, other than penetrations below 250 feet. Thus, the intended design was not strictly adhered to; however, this was viewed as no practical significance because the very few loss cases occurred from "random" malfunction of the data collection device.

Subsequent to variance partitioning, the terms of the model were printed and the resulting components tested for significance. Tables 7 through 11 give the results of the partitioning with the sums of squares percent, SS(%), reflecting the percentage of the total sums of squares explained by each component sources of each analysis. From examination of table 7, one can see that only a fair percentage (29.8) of the penetrations below 250-foot variance was explained. This contrasts with the good fits seen in tables 2, 3, and 4 where 49.8, 48.2, and 50.3 percent, respectively, of their criteria were explained. Likewise, the excellent fit (89.8 percent) of the standard deviation in g data, contained in table 5, contrasts sharply with the lesser percentages for the other criteria. No explanation for the differences in the predictability of the various criteria is offered except that penetrations below 250 feet provide only a discrete approximation of a continuous distribution function while the other metrics provided continuous estimates of such functions. As a whole, the fit of the model was satisfactory and further finer-grained modeling of the data was contraindicated.

⁶Dixon, W. J., ed. BMD Biomedical Computer Programs. Los Angeles, Calif., University of California Press, 1975.

⁷Overall, J. E. and D. K. Spiegel. "Concerning Least Squares Analysis of Experimental Data," PSYCHOLOGICAL BUL, Vol. 72, 1969, pp. 311-323.

Table 7. Summary of Analysis of Penetration Below 250 Feet

Source	Sum of Squares (Percent)	Degrees of Freedom	Mean Square (Percent)	F Ratio	Probability
Subjects (S)	10.59	8	1.324	3.43	< 0.05
Runs (R)	8.49	26	0.327	—	NS
Downlook (D)	1.46	2	0.730	1.90	NS
Focus (F)	0.35	2	0.178	—	NS
Separations (S)	2.61	2	1.304	3.39	< 0.05
D * F	0.65	4	0.164	—	NS
D * S	0.94	4	0.236	—	NS
F * S	0.84	4	0.210	—	NS
F * D * S	3.84	8	0.480	1.25	NS
Error	70.22	182	0.385	—	—
Total	100.00	242	—	—	—

NS = nonsignificant.

Table 8. Summary of Analysis of Average Altitude Above 250 Feet

Source	Sum of Squares (Percent)	Degrees of Freedom	Mean Square (Percent)	F Ratio	Probability
Subjects (S)	36.51	8	4.564	16.29	< 0.005
Runs (R)	5.66	26	0.22	—	NS
Downlook (D)	1.59	2	0.795	2.84	NS
Focus (F)	1.08	2	0.540	1.93	NS
Separations (S)	0.12	2	0.060	—	NS
D * F	0.49	4	0.245	—	NS
D * S	0.06	4	0.015	—	NS
F * S	0.47	4	0.117	—	NS
F * D * S	3.86	8	0.483	1.72	NS
Error	50.16	179	0.280	—	—
Total	100.00	239	—	—	—

NS = nonsignificant.

Table 9. Summary of Analysis of Average g on Pilot

Source	Sum of Squares (Percent)	Degrees of Freedom	Mean Square (Percent)	F Ratio	Probability
Subjects (S)	29.60	8	3.70	12.79	< 0.005
Runs (R)	11.48	26	0.441	1.53	NS
Downlook (D)	0.76	2	0.380	1.31	NS
Focus (F)	0.16	2	0.080	—	NS
Separations (S)	1.93	2	0.965	3.33	< 0.05
D * F	0.18	4	0.045	—	NS
D * S	0.50	4	0.125	—	NS
F * S	1.00	4	0.250	—	NS
F * D * S	2.56	8	0.320	1.106	NS
Error	51.79	179	0.289	—	—
Total	100.00	239	—	—	—

NS = nonsignificant.

Table 10. Summary of Analysis of Standard Deviation in Altitude

Source	Sum of Squares (Percent)	Degrees of Freedom	Mean Square (Percent)	F Ratio	Probability
Subjects (S)	35.22	8	4.403	15.85	< 0.005
Run (R)	5.44	26	0.209	—	NS
Downlook (D)	2.35	2	1.175	4.23	< 0.025
Focus (F)	0.67	2	0.335	1.21	NS
Separations (S)	0.59	2	0.295	1.06	NS
D * F	1.03	4	0.258	—	NS
D * S	0.96	4	0.240	—	NS
F * S	0.45	4	0.113	—	NS
F * D * S	3.56	8	0.445	1.60	NS
Error	49.72	179	0.278	—	—
Total	100.00	239	—	—	—

NS = nonsignificant.

Table 11. Summary of Analysis of Standard Deviation in g on Pilot

Source	Sum of Squares (Percent)	Degrees of Freedom	Mean Square (Percent)	F Ratio	Probability
Subjects (S)	83.85	8	10.480	183.02	< 0.005
Run (R)	1.37	26	0.05	—	NS
Downlook (D)	3.17	2	1.585	27.68	< 0.005
Focus (F)	0.12	2	0.060	1.05	NS
Separations (S)	0.21	2	0.105	1.83	NS
D * F	0.20	4	0.050	—	NS
D * S	0.03	4	0.008	—	NS
F * S	0.17	4	0.042	—	NS
F * D * S	0.63	8	0.787	1.38	NS
Error	10.25	179	0.057	—	—
Total	100.00	239	—	—	—

NS = nonsignificant.

DISCUSSION

J.N.C.Cooke, IAM Farnborough: What effect is produced if there is noise or distortion from one TV camera? Are there vibration problems in actual use?

Author's reply: In fact this effect is very important and can reduce the display's quality. There are no vibration problems.

THE PRESENTATION OF CARTOGRAPHIC INFORMATION IN PROJECTED MAP DISPLAYS

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SUMMARY

Projected map displays dramatically reduce the navigation workload of low altitude high speed flight in single seat aircraft. Their advantages include automatic display of maps, aircraft present position and track, reduced head-in-cockpit time, and improved correlation of navigation systems and ground mapping sensor data. Yet pilots continue to use hand-held maps in aircraft fitted with map displays. One reason for this is the poor legibility of the map image. Many factors affect legibility including the resolution of the microfilm and optics, the display brightness, the viewing distance and the map reduction/magnification ratios. A basic problem, however, is the unsuitability of conventional cartography for use in projected map displays. This paper describes recent and on-going human factors research on the information content, coding and utilisation of maps and charts designed specifically for projected map displays. Particular issues are discussed such as clutter, colour coding, red light legibility, relief representation, reverse format "black" maps and radar-map matching; general design principles are also derived.

1. GEOGRAPHIC ORIENTATION IN LOW ALTITUDE HIGH-SPEED FLIGHT

The maintenance of geographic orientation is a major problem in single-seat low altitude tactical operations. A study (1) of 959 records of low altitude attack training missions showed that 10% were aborted because the pilot got lost. In another 17%, the pilot got lost somewhere en route, but managed to reorientate and find the task area, usually arriving late. Training records of 126 low altitude pilots showed that 80% got lost on at least one mission and one man got lost on every mission.

The most common cause of geographic disorientation in the above surveys was mis-identifying or missing checkpoints. En route navigation accuracy of less than 0.5 nautical miles is essential to remain orientated at low altitude and this can be achieved by conventional map reading techniques, time and distance estimation, and accurate heading control, if supported by extensive pre-flight planning. But the workload of controlling the aircraft and maintaining ground clearance places heavy demands on the pilot in flight so map reading has to be restricted to brief glimpses. The problem is further complicated by the limited field of view outside the cockpit due to the oblique perspective and terrain masking, and by the high angular velocities of features. Under these conditions the pilot must think ahead, anticipate features and make decisions on information that is often inadequate and unreliable. The pilot is highly motivated to fly the sortie as planned, and in the stress of the situation false hypotheses about the identity of ground features are made and accepted, without checking. Expectancies are developed about what will be seen on the ground and when off-track there is a tendency to "fit the map to the ground", forcing the view outside the aircraft to correspond to the planned route.

This kind of human error can be prevented by automating the task of monitoring geographic position, and thus unburdening the pilot of navigation workload. A variety of automatic map displays have been developed to achieve this and three major types can be distinguished:

- (1) Direct-View Map Displays: A strip map on motorised rollers, with a cross-track cursor indicating present position, or a fixed map with moving cross wires showing the aircraft's location.
- (2) Optically Projected Map Displays: A microfilm transparency of the original map is back projected onto a display screen. The aircraft's present position is indicated either by a moving symbol against a fixed map image, or by a fixed symbol against a moving map image.
- (3) Electronic Map Displays: All the displayed information, including the map, is generated electronically on a cathode ray tube or by light emitting diodes.

Currently, direct-view map displays are favoured in helicopters and transport aircraft because of their simplicity and cheapness. All electronic map displays are under development and are likely to be incorporated in future generations of strike aircraft if the problems of cost, weight, computer capacity and colour imaging are satisfactorily resolved. Meanwhile, projected map displays are preferred for long range low altitude strike aircraft because the large map storage capacity and flexibility offer significant improvements over direct-view displays. More detailed descriptions of contemporary map displays are available (2,3).

The purpose of the present paper is to discuss the human factors associated with the use of projected map displays in low altitude high speed flight, and to emphasise the problems of the presentation of cartographic information. A summary will be given of recent and on-going research on map design conducted jointly by cartographers at the UK Mapping and Charting Establishment and by psychologists at the RAF Institute of Aviation Medicine.

2. PROJECTED MAP DISPLAYS

Projected Map Displays (PMDs) use topographical maps, rectified and photographically reduced onto continuous 35 mm filmstrip, from which a map image is presented to the pilot by optical magnification and back-projection. The filmstrip is driven from the aircraft's navigation data sources (VOR/DME, doppler, or inertial platform) and the projected image thus gives a continuous, automatic indication of the aircraft's current position and track. The major advantages of PMDs can be summarised as follows:

- (1) Workload: They reduce pre-flight planning time and provide an immediate and continuous monitoring of the aircraft's geographical position. Hence, navigation workload and head-in-cockpit time are substantially reduced and the pilot can devote more attention to control. Anticipation and recognition of features is improved, so that the updating of the navigation system is facilitated.
- (2) Map Storage: PMDs store and display large areas of mapping at a variety of scales. Up to 280 m² of original cartography can be stored on 35 mm microfilm in some displays, giving coverage of the whole operational range of the aircraft, without the handling and stowage problems associated with paper maps.
- (3) Navigation Data Storage: A variety of navigation information can be stored and displayed in addition to maps, e.g. track marker and steering information, and digital readouts of positions, speeds, and distance and time from destination. By presenting navigation information superimposed on a map, the data is easily interpreted and the likelihood of gross navigation errors is reduced.
- (4) Correlation of Navigation Systems: PMDs provide a means of cross-checking the outputs of navigation systems such as doppler, radar, inertial platform and visual reference to the ground.
- (5) Man-Computer Linkage: They are also a convenient means of communicating with the on-board navigation computer, checking its integrity, updating its accuracy and inputting navigation problems.

When considering the disadvantages of PMDs, it is clear that there are many problems associated with their use, varying in severity with different types of PMDs. Cost and weight are important factors, and the comparatively large amount of cockpit space occupied by a PMD is difficult to justify for a single display function; a diameter of 150 mm across the display face is common. The inability to annotate the map image with essential route-plan and tactical information is frequently cited as a major disadvantage compared with hand-held maps. Lack of PMD annotation facilities is one of the main reasons why aircrew in aircraft with PMDs continue to refer to hand-held maps in flight for route-plan information. However, this problem is not intractable. Film annotation techniques are being developed, and displays are available that optically combine a CRT with the map image, permitting superimposition of route-plan information (Astronautics P-N 110150 and Ferranti COMED). The development of combined CRT and PMD displays has the added merit of attaining superimposition or independent presentation of sensor data, such as radar and infra-red imagery. This makes the unit a highly flexible, multi-function display that is easier to justify in terms of cockpit space.

On balance, the advantages of PMDs far outweigh their disadvantages; most aircrew regard them as valuable systems for low altitude, high-speed flight, and imperative for single seat operations.

3. EARLY DESIGN ISSUES

During the development of PMDs, a number of design issues arose concerning the presentation of the map information to the pilot (4). These have largely been resolved through operational experience with PMDs, but they illustrate some of the major human factor problems encountered with this form of display.

3.1 Fixed Map or Moving Map

One of the earliest design problems concerned whether the map or the present position indicator should move. Image speeds of PMDs do not significantly degrade visual acuity so a fixed map display is not predicated. The major controversy was largely conceptual. On the basis of empirical experiments, it was concluded that pilots conceive of the earth as the fixed component of the navigation system (5). Therefore, in map displays, the map should be the fixed component against which the aircraft should move. However, practical experience has shown that the reverse is preferred by most aircrew. This is primarily because a moving symbol format necessitates frequent map changes as the symbol approaches the edge of the display, where the important 'view ahead' distance is reduced. Consequently, nearly all contemporary displays, both direct-view and projected, employ a moving map format and are thus called moving map displays.

3.2 Map North-Up or Track-Up

A related design issue concerned the choice of map orientation; should it be north-up or track-up, with the track line pointing to the top of the display? Early map displays, with a fixed-map format, displayed the map orientated north-up on the grounds that it would facilitate reading of map lettering. More recently, with moving map formats, it has become apparent that when pilots are given the option they prefer the map to be orientated track-up. Most aircrew orientate hand-held maps track-up because this facilitates correlation of the map with the view-ahead of the aircraft. Only occasional reference to the north-up mode is required when lettering needs to be read. Most operational displays now can operate on either north-up or track-up modes, as selected by the pilot.

3.3 Centred or De-Centred Present Position

Early PMDs, with only a north-up mode, were designed with the aircraft symbol in the centre of the display. This was partly for convenience, but it also ensured that at all times half the display was view-ahead. However, with moving map formats and track-up modes, the viewing distance can be increased by having the present position indicator at the bottom of the display. This also has advantages for correlation with ground mapping radar where the sweep origin is at the bottom of the CRT. The centered position remains useful for flight planning and when programming and reading-in waypoint co-ordinates. Thus, it is retained as an option in the most recent displays. Survey data has shown that the preferred position for the de-centered aircraft symbol is 25% up from the bottom of the display (3).

To summarise, most contemporary operational PMDs have a moving map format, with optional north-up and track-up modes, and a present position indicator centered and de-centered for selection at will.

4. LEGIBILITY

Chart legibility is an important factor in low altitude high speed (LAHS) flight, if only because of the limited time available for map reading. Although PMDs have automated the monitoring of geographical positions, the pilot still needs to read the chart to compare present, indicated and planned positions, to anticipate check-points, turns, targets and hazards, and to read off air information. Consequently, chart legibility requirements are important for PMD designers as well as for cartographers.

Survey data has shown that most PMD users are dissatisfied with the legibility of the chart image. A survey of 40 RAF Harrier pilots found that in sunlight, 100% felt that the PMD image was not clearly legible; 41% thought that the chart image was "somewhat less legible" than an identical hand-held chart, and the remaining 59% thought that the image was "much less legible". The inferiority of the PMD image is one of the main reasons, but not the only one, why PMD users continue to carry hand-held charts. Hand-held charts are also needed to act as a back-up in case of system failure, and to provide tactical and route-plan information.

Many factors affect PMD legibility. The major parameters are listed in Table 1. This table does not include human factors such as familiarity with the map symbols and the geographical area, and the luminance adaption level of the operator.

TABLE 1 - FACTORS AFFECTING PMD LEGIBILITY

Cartographic Factors	Display Factors	Environmental Factors
Map Scale Symbol size Symbol contrast Symbol colour Clutter	Photographic reduction Microfilm resolution Optical magnification Spectral sensitivity of film emulsion Lens resolution Screen resolution Reflectance off the screen Open-gate display luminance	Viewing distance Vibration Ambient illumination

Most map display research has assumed that cartographic factors, other than map scale, cannot and need not be manipulated. It is generally considered that displays can be designed to produce an acceptable image with conventional maps and charts (3,6,7,8). Consequently, attempts to study PMD design requirements have been mainly concerned with the physical parameters of the display design that affect the resolution, size and contrast of the image.

4.1 Image Resolution

Resolutions achieved in the microfilming and optical processes are major limiting factors on display legibility. Up to 100 line pairs per mm are possible in the positive microfilm print, with some enhancement of the original contrasts and colour saturations (9). The resolution of the final image is dependent on both the film and lens resolutions, and the resolving power of the combination can be determined by the following equation:

$$\frac{1}{F} + \frac{1}{L} = \frac{1}{C}$$

where

F = resolving power of the film

L = resolving power of the lens

and C = resolving power of the combination.

Resolutions of between 3 and 8 line pairs per mm in the final image have been reported for PMDs, the majority falling between 4 and 6 line pairs per mm. It can be shown that simple forms of alphanumeric symbol (e.g. upper case Arabic) can be theoretically resolved by a system of 3-4 line pairs laid across the symbol, if it subtends more than 6-8 minutes of arc. But more line pairs are required if symbols in non-optimum fonts or with low contrasts are to be recognised (3).

Screen grain may also affect the resolution of the final image. However, this factor can be eliminated by vibrating the screen, as in the Harrier PMD (10).

4.2 Image Size

Within the resolution limits of the microfilm and projection system the map information actually resolved is determined by the degree to which the maps are photographically reduced onto microfilm and optically magnified when projected, i.e. the image size. Comparatively high linear reduction factors of about x 15 are common because of the need to provide a large area of map coverage, as dictated by the operational range of the aircraft. This jeopardises the resolution of small map detail. For a given area, the larger the scale of the original mapping, the greater is the reduction factor and subsequent degradation.

When projecting the image from the film, factors of optical magnification greater than microfilm reduction (over-magnification) are used to improve the legibility of the chart image and to compensate for the abnormally long cockpit viewing distances of panel-mounted displays (760 mm), compared with handheld charts (variable, up to 500 mm). Recent displays magnify the map image by linear factors as large as $\times 1.63$ to achieve this effect. However, whilst improving legibility, over-magnification has the disadvantage of decreasing the chart area displayed, reducing the important "view ahead" distance. Survey data has shown that a good estimate of the minimum view ahead distance for light jet aircraft is 20 nautical miles, equivalent to 65 mm at 1:500,000 and 130 mm at 1:250,000 scale (3). Given this requirement for view ahead, the degree of over-magnification of the chart image that can be achieved will depend on the size of display face, and the location of the present position indicator (centered or de-centered). It is unlikely that further increases in display size will be acceptable because of limitations on cockpit space. Furthermore, the evidence suggests that current sizes (approximately 150 mm diameter) are preferred by aircrew and are also close to the optimum for maps viewed at 760 mm, judged by the efficiency of eye fixations and search patterns during map reading (11).

4.3 Image Contrast

High image contrasts are extremely important requirements for PMDs. Ambient cockpit illuminations of the order of $3,000 \text{ cd/m}^2$ and reflections off the display face make it difficult to produce a back-projected image bright enough for adequate image contrasts. To make the map image independent of ambient illumination, field lens optical systems have been used which form the primary map image within the display, where it cannot be reached by extraneous light, unless light enters the display by the exit pupil of the lens system (10). However, the limited viewing angle of the field lens system limits the pilot's head movement and indifferent optics easily result in image flatness problems and geometric distortion of the map image. Operational experience with simple back-projection systems in which the image is formed at the display face, such as used on the Jaguar, has shown that adequate contrast can be obtained for most map symbols if a bright light source is used with anti-reflectance screen coating and enhanced film contrast. The Jaguar PMD has a screen brightness of approximately $3,600 \text{ cd/m}^2$.

A more detailed discussion of the relationships between the parameters discussed above and their consequences for PMD design criteria is available (3).

5. CARTOGRAPHIC FACTORS

Cartographic solutions to PMD legibility problems are rarely sought because of the high cost of map production and reluctance to question the excellence of conventional cartography. It is often mistakenly assumed that, because aircrew are rarely heard to complain about their maps, there is little need, nor room, for improvement. This is a false assumption because aircrew are rarely faced with alternatives and must use the maps they are given. Attempts to introduce a new 1:250,000 map series in UK in place of an existing series met with severe criticism, particularly from fast jet users, and demonstrated that when aircrew have a choice they can be quite discerning (12). Recent attempts to quantify aircrew opinion using subjective scaling techniques have shown that if aircrew are formally consulted, and if options are made available for comparison, many improvements can be made to match the map design more closely to the user's requirements (13,14). Special purpose maps are needed for specialised roles, such as PMDs and LAHS flight, and it is interesting to note in this context that a survey of users of a variety of PMDs found that the only PMD whose chart image was considered to be reasonably legible was the one PMD that used a specially designed map (3).

The unsuitability of conventional large scale topographical maps for PMD applications has long been recognised (9,15). The 1:250,000 scale Joint Operations Graphic (JOG) Series 1501-Air has attracted much of this criticism. Intended for a variety of air and ground uses, the JOG attempts to give as comprehensive a plan of features as possible, cramming as much detail onto the map as space will allow, and aiming to maximise positional and representational accuracy. This has forced the adoption of a coding specification with small symbols, small type and fine line detail which make the map difficult to use in PMDs, even with the most favourable microfilm reduction factors. Considerable user dissatisfaction was expressed with the legibility of the JOG when it was fitted in the Harrier PMD and it has since been replaced by the 1:500,000 Tactical Pilotage Chart (TPC) and the AFCENT Low Flying Chart (LFC). Although the TPC and LFC are less accurate and less detailed, their content and coding are more appropriate to the airborne environment and to the information needs of the PMD user.

To investigate more closely the legibility requirements for PMD maps, two experiments have been carried out at the RAF Institute of Aviation Medicine in conjunction with the UK Mapping and Charting Establishment.

6. EXPERIMENT I - AN EVALUATION OF AN EXPERIMENTAL MAP (16)

An experimental 1:250,000 map was produced to a specification based on ergonomic principles, knowledge of map-microfilming techniques, and on practical cartographic considerations. A laboratory evaluation was conducted in which the legibility of a variety of topographic (point, linear, area) and alphanumeric symbols were compared with corresponding symbols on a conventional JOG map of the same area and scale. Forty-eight subjects completed a symbol identification task under normal (paper) and simulated PMD conditions, using two microfilm reduction factors ($\times 19$ and $\times 14.5$) chosen to represent the range of practical reductions considering microfilm resolution and map storage capacity. The results showed statistically significant differences ($p < 0.01$) between viewing conditions, maps, symbol sets and individual symbols. Projected viewing increased response times, reduced information transmission and gave 155% more errors than normal viewing. The original map gave less transmission, more systematic errors (system noise) and 33% more errors than the experimental map under projected conditions. The increased errors on the original map ranged from 3% more errors for area symbols to 84% for alphanumerics.

Increased map legibility was achieved by a variety of symbol and background coding effects. It was possible to identify five general design principles, relating to symbol and background coding, that would improve the legibility of topographical maps for PMD applications.

6.1 High Contrasts

The use of white for the lowest elevation interval is particularly effective as information tends to be densest in low lying regions. In addition to optimising contrasts, the white background permits the maximum flexibility in overprinted colour coding, eliminating induced colour distortions. Boxed spot heights, cleared of background detail, are an essential requirement. As a general rule, reflectance differences of 45% between overprinting and background on the original map are minimal for legibility under PMD conditions.

6.2 Exaggerated Physical Dimensions

Line heights, character heights and stroke widths, minimal for normal viewing, need to be increased at least twofold to maintain legibility under PMD conditions. Five point type is commonly used on conventional topographical maps, but as a general rule at 760 mm viewing distance and x 1.50 overmagnification, eight point type (upper case height 1.78 mm, stroke width 0.3 mm) are minimal legible characters in familiar letter sequences. Critical characters (spot heights, grid notation) need at least twelve point type (height 2.8 mm, stroke width 0.51 mm) to be legible in low contrast contexts. These dimensions are substantially less than normally recommended for visual displays under comparable conditions and illustrate the extent to which space restrictions and information density on maps are serious constraints on design.

6.3 Simple Symbol Forms with High Association Value

Pictorial symbols are preferable to feature names and functional labels, providing the symbols are bold and simple in form and have an easily recognised meaning. Abstract shapes can be acceptable if they are well known conventional symbols, such as the circle symbol for railway stations. The primary rules for designing map symbols are:

- a. Contrasts should be maximal.
- b. Shape should be distinctive in general outline, but not in fine detail.
- c. Minimum size should be determined by the smallest component that has to be recognised.
- d. The symbol should have high association value and compatibility between coding and meaning.

6.4 Low Confusability

Some similarity is inevitable on maps with so many categories of information; it is also desirable because of the need to show relationships between features (map syntax) by hierarchical coding, using combinations of similar characteristics (conjunctive coding) and dissimilar characteristics (disjunctive coding). Confusions tend to occur between symbols that have similar coding and similar meanings, but they become serious higher up the symbol hierarchy where features are qualitatively distinct. Colour coding is valuable for distinguishing major categories of information, but colour differences need to be gross, probably different hues, otherwise serious confusions are likely to occur, such as between rivers and power lines coloured in different blues without a distinctive shape code for the latter. Shape coding should be used for differences within major classes, such as between normal and narrow gauge railways, but again size should be determined by the smallest component that has to be recognised to prevent confusion.

6.5 Reduced Information Content and Clutter

Information density and clutter are often high on maps and are important determinants of user acceptability, particularly in LAHS flight. Reductions in map content and greater visual separability through colour coding are essential to offset the effects of increasing the size and saliency of important information on PMD maps.

7. EXPERIMENT II - WOOD SYMBOLS (17)

Isolated woods are useful navigation features in LAHS flight. Methods of portraying woods on aeronautical charts are heavily constrained by the legibility of other cartographic information. Cartographers use a variety of techniques to alter the balance between woods and base map legibility, principally vignetting (banding), outlining, and saturation/brightness variation. A laboratory experiment was carried out under simulated PMD conditions, using five 1:500,000 TPC maps of the same area demonstrating various styles of woodland symbols. Forty subjects completed a simple pattern recognition task, matching selected segments of wood symbols (woods recognition task) and map backgrounds (base recognition task) to the five test maps and to two control maps showing the woods pattern only and the base map only. Significantly longer times and more errors ($p < 0.01$) occurred when matching to the test maps than when matching to the control maps. This indicated that with all the symbol types, both woods and base map were less legible on the test maps than when the woods and base were displayed independently. Mean response times for the recognition of woods increased by over 300%, compared with a 135% increase for base recognition. Analysis of variance of times showed significant differences on times between the test maps on woods recognition ($p < 0.01$), but no significant differences occurred between the maps on base recognition.

The results confirmed the initial assessment that irrespective of the symbol type, it is extremely difficult to extract useful information about wood shapes from 1:500,000 scale maps in areas where the woods pattern is detailed and complex. Furthermore, all the symbol types had a substantial detrimental effect on the legibility of other map information, particularly relief, and there can be little justifica-

tion for tolerating this reduction in legibility when the ability to use the woods shapes is seriously questioned. Uniqueness is a major determinant of navigational significance, and consequently, it is recommended that the woods should only be depicted when they are distinctive and isolated. In areas of extensive woodland, maps should be cleared of wood detail to minimise unnecessary effects on map legibility. Comparisons of the individual types on wood recognition broadly agree with what would be anticipated on the grounds of ink saturation, brightness and colour contrast; solid, saturated green tints are superior to vignetting and light green tints. Particularly poor performance on base recognition with narrow vignetting is probably caused by the excessive clutter due to the doubling of edge contrasts; poor performance on the recognition of woods depicted with vignette symbols may have been caused by poor figure-ground segregation.

8. COLOUR REQUIREMENTS

Chromaticity is an important requirement for complex visual displays. Colour coding reduces clutter, increases visual separability and facilitates search for and location of information by virtue of its attention-getting qualities.

PMD images are frequently criticised because of poor colour quality. Many of these criticisms can be traced to the use of maps designed to be legible under the red lighting provided in cockpits to help maintain dark adaption at night. Specifications aimed at red light legibility restrict map colours to short wavelength hues (purples, blues and greens) and to colours with large grey/black components. Although hue differences become indiscernible under red light as the map takes on a monochromatic appearance, short wavelength colours will continue to show brightness contrast against light backgrounds. Colours that lose contrast under red light, such as reds, oranges and yellows, are omitted from map specifications, although they may be attention-getting under daylight, white light and PMD conditions. Such efforts to achieve red light legibility have demonstrated considerable cartographic ingenuity, but they are valueless unless pilots use red light to illuminate their maps. A recent IAM survey (18) has indicated that this is not common practice. A relatively small percentage of aircrew (21%) claimed to use red light for the illumination of topographical maps during critical night, low-level operations. The great majority use white (54%) or red-white (pink) mixtures (25%), though all have optional red-white auxiliary map lights fitted to their aircraft stations. Use of red lights bears no clear relationship to operational roles or aircrew duties, to ratings of the importance of night vision, or to age and night low-flying experience, but depends on the colour of the instrument lighting of the current aircraft type and on experience of white cockpit lighting. In aircraft fitted with red instrument lighting, the percentage using red map lights is small (23.8%) but the percentage is even smaller in aircraft fitted with white instrument lighting (10.9%, $p < 0.001$). Closer examination of aircrew currently flying aircraft with red instrument lighting reveals that the choice of map light colour depends on previous flying experience with aircraft fitted with white instrument lighting; significantly fewer use red map lights (15.6%) among those who have previously flown with white instrument lights, than among those who have only flown with red instrument lights (28.2%, $p < 0.001$). The great majority of pilots considered that the advantages gained by using red lighting on maps in terms of improved night vision are far outweighed by the disadvantages in terms of loss of colour coding. Consequently, most aircrew use dimmed white hand-held torches to illuminate their maps at night and restrictions on colour coding are an unnecessary disadvantage (18).

The use of white torch lighting is consistent with experimental evidence which shows that the saving in night vision sensitivity with red lights is a function of the duration, intensity, and retinal location of the exposure; if the exposures are short, of moderate intensity and confined to the centre of vision (fovea), as in map reading, white light can be used with little loss of dark adaption (19). Psychological factors such as training, conformity, habits and attitudes largely determine preference for red or white light. With re-education and training in the efficient use of white light, and the provision of better map lighting, red light legibility is likely to become an out-of-date requirement, and an unnecessary restriction on map coding. Map series of the future are unlikely to be constrained in this way.

A further source of poor colour imaging derives from the microfilming process. When conventional aeronautical charts are photographed on microfilm and projected in PMDs, enhancement of the original contrast and colour saturation occurs and this may be beneficial to legibility. But changes in the colour hues are also apparent and these may reduce chart legibility, particularly at the low display brightness used at night. Low Flying Charts used in PMDs in North West Europe have been criticised for this reason. Inaccurate reproduction of the original hues occurs because of differences in the spectral sensitivity of the film and the human eye. Changes in the hues are difficult to predict because they depend on the microfilm emulsion and the spectral composition of the printing inks, which is not normally known. Further research is needed to investigate the problem and to identify optimum chart colours, taking into account the microfilming and projection processes and the information requirements of the user. To this end, the IAM has recently been tasked to determine a colour specification for Low Flying Charts, suitable for day and night use in PMDs in North West Europe, which will be reproduced on "Cibachrome" microfilm.

In response to this request, a series of laboratory experiments are being conducted to obtain data on the discriminability and relative conspicuity of colours from the Directorate of Military Survey Ink Specimens Booklet.

(1) Discriminability Testing

Selected colour chips have been mounted in pairs on cards and photographed on microfilm, using the identical process as for PMD filmstrips. Projected images of the colour pairs will be viewed by trained subjects who will make similarity/disimilarity judgements to provide quantitative measures of the discriminability or confusability of the colours. This data will be used to develop a low - confusion colour code.

(2) Conspicuity Testing

Selected colour chips have been mounted on cards containing a random array of same-size, neutral colour (grey) chips, and photographed on microfilm using the PMD process. The positions of the colour chips within the cards are varied. Projected images of the cards will be presented to subjects under low brightness intensity and subjects will be required to search for, locate and identify the target colours. Performance on the task will provide a measure of the attention-getting qualities or visual conspicuity of the projected colours.

From these experiments it will be possible to derive a set of colours that are highly discriminable and are not easily confused, and whose attention-getting qualities can be matched to the importance of the information to the user.

9. RELIEF REPRESENTATION

A parallel programme of research is being carried out to determine the optimum layer colours for representing relief on Low Flying Charts for PMD applications in North West Europe. Earlier research indicated that relief representation and clutter are the major determinants of user acceptability of topographical maps for LAHS flight (14). In low-level visual navigation relative elevation and visualisation of relief are more important than absolute height and consequently most topographical maps rely heavily on layer tints and hill shading for relief representation. Currently there are two schools of thought on how layer tints should be determined. One argument supports the familiar practice of gradual colour change, predominantly within one hue, on the grounds that elevation is on a continuous scale and layer colours on maps should also appear continuous. The second approach, used on the JOG and TPC, favours distinctively different layer colours as a colour code to specific elevation intervals. These colours and their corresponding elevation intervals are applied worldwide, and it is assumed that the user can memorise and recall them without reference to the map legend.

In order to study the merits of different systems of relief layering, experimental material has been prepared by the Mapping and Charting Establishment illustrating a variety of colours, percentage printing screens and printing techniques. Many colours have been eliminated from consideration on the grounds that they provide inadequate background contrast (< 45%) for overprinted information. Initial experiments have been conducted using the magnitude estimation technique to establish the psychological dimensions of perceived colour change corresponding to changes in percentage printing screens. On the basis of these results, ten sets of eight layer tints, with subjectively equal 'steps', have been compiled for further testing. The number of steps and printing inks required to produce them have been chosen to be compatible with the specification for Low Flying Charts in North West Europe.

A second experiment is planned to examine the effectiveness with which these sets of tints convey an impression of change in height and relative elevation when photographed and projected from Cibachrome microfilm. The tints in each set will be arranged in rows similar to cross sections across a map with varying elevation. These coloured arrays will be photographed and projected. Subjects will be required to identify tints representing relatively high ground. Performance on the task will provide a measure of the relative effectiveness of each set of tints under PMD conditions. The most effective set will be proposed for use on Low Flying Charts designed according to the colour specification derived from the discriminability and conspicuity research discussed previously.

10. COMBINED DISPLAYS

A requirement has recently arisen to produce maps for combined CRT and PMD displays (CRPMDs) in which the map image is optically superimposed on a radar picture (20). Radar - map matching, as it is called, has particular advantages when flying at night or in poor weather conditions when radar is often the only reliable source of terrain information. Viewed by itself, a radar picture is almost the ultimate in "booming buzzing confusions". But combined with a map of the same area, projected at the same scale, the radar returns immediately become meaningful, the map acting as a very useful perceptual aid. CRPMDs are claimed to increase radar interpretability, to facilitate the early recognition of features, and to permit continuous monitoring of the navigation system. When the images appear displaced the map can be aligned by a manual control so that error in the navigation system may be corrected.

One of the basic design problems is to achieve a combined image in which the radar returns are sufficiently bright to be seen against the map image. Field lens/transfer lens optical systems are used to make the combined image independent of ambient brightness. Another possible solution is to reverse the format of the map so that the background is predominantly dark with the information items overprinted in light colours. A variety of reverse format "black maps" have been produced and evaluated in a CRPMD simulator at the Royal Aircraft Establishment, Farnborough. Ad hoc assessments have shown that although black maps optimise the brightness contrasts of overlaid radar, they are at a serious disadvantage compared with conventional formats with regard to relief representation. In mountainous regions, the only useable radar returns come from relief features, such as reflections from steep slopes and ridges. The conventional way of portraying slopes is by hill shadow shading, but these shadows can only be seen against a light background. Consequently, the shadow shading technique is not applicable to black maps. Failure to give adequate relief representative on black maps favours the use of modified conventional maps for radar map-matching. Hill shadow-shading has to be enhanced and the map symbols designed for legibility under low brightness conditions. Map content should also be limited to radar significant features only (4).

Empirical experiments are planned to obtain data on operator performance on radar-map matching using different display options. In particular, it is proposed to examine the relative merits of a cursive radar sweep compared with a permanent and complete radar picture. Factors affecting radar-map mismatch detection performance will be studied and the operator effects of map design parameters will be quantified.

11. CONCLUSIONS

Research has shown that there are important perceptual limitations on the ability of aircrew to extract information from the topographical maps used in PMDs for LAHS flight. Factors such as image size and contrast have been investigated in other forms of information displays, and the limits for specific PMD applications merely need to be identified. Relatively little is known about the more complex effects of clutter, figural-goodness and visual balance, yet they are major determinants of PMD legibility. Traditional cartography has been concerned with packing as much information on maps as possible, emphasizing the "information store" function of maps at the expense of "information display" parameters. But far more information is normally displayed than can possibly be used in LAHS flight. By taking greater account of the perceptual and cognitive limitations of the LAHS user and by selecting information for portrayal on maps on a more rigid need-to-know basis, it should be possible to make dramatic improvements in PMD legibility without compromising other important requirements such as map scale, accuracy and view ahead.

12. REFERENCES

1. McGrath, J.J. & Borden, G.J. Geographic Orientation in Aircraft Pilots: A Problem Analysis. (1963) Human Factors Research Incorporated Technical Report 752-1.
2. McGrath, J.J. Contemporary Map Displays. (1972) AGARD Conference Proceedings 96, pp 14:1-16.
3. Carel, W.L., McGrath, J.J., Hershberger, M.L., Herman, J.A. Design Criteria for Airborne Map Displays. (1974) JANAIR Report No. 731101.
4. Taylor, R.M. Human Factors in Aircraft Map Displays. (1975) RAF Institute of Aviation Medicine Report No. R557.
5. Roscoe, S.N. Airborne Displays for Flight and Navigation. Human Factors. Vol. 10 Part 4 1968, pp 321-332.
6. Laymon, R.S. An Experimental Comparison of Two Map Display Modes. Human Factors. Vol. 10 Part 5 1968, pp 497-504.
7. Hitchcock, L. Readability of Videotaped Moving Map Displays. (1970) Human Factors Research Incorporated Technical Report 101-1, pp 167-173.
8. Wong, K.W. & Yacoumelos, N.G. Identification of Cartographic Symbols from TV Displays. Human Factors. Vol. 15 Part 1 1973, pp 21-31.
9. Honick, K.R. Pictorial Navigation Displays. Cartographic Journal. Vol. 4 1964, pp 72-81.
10. Briggs, T.S. A Navigation Computer and Display for Harrier. (1972) AGARD Conference Proceedings 96, pp 12:1-14.
11. Enoch, J.M. Effect of Size of Complex Display on Visual Search. J.Opt.Soc.Am.Vol. 49 Part 4 1959, pp 280-286.
12. Lakin, F.H. A Further Evaluation of the Joint Operations Graphic Series 1501 (Air). (1972) Army Personnel Research Establishment Report No. 18/72.
13. Murrell, J.F. Aircrew Choice of Information on a Topographical Map. (1970) RAF Institute of Aviation Medicine Report No. 253.
14. Taylor, R.M. Subjective Assessments of 1:250,000 Scale Maps for En Route Low Altitude High Speed Navigation (1974) RAF Institute of Aviation Medicine Report No. 544.
15. Roscoe, S.N. The Case for the Moving Map Display. Information Display. Vol. 4 Part 5, 1967, pp 44-66.
16. Taylor, R.M. Projected Map Display Legibility: An Evaluation of an Experimental 1:250,000 Topographical Map. (1976) RAF Institute of Aviation Medicine Report No. 545.
17. Taylor, R.M. Shape Recognition on Aeronautical Charts: A Study of Woodland Symbols. (1975) Paper presented to the ICA Symposium on Cartographic Communication, London, September 13-19.
18. Taylor, R.M. An Investigation into Operational Requirements for Map Reading at Night (1976) RAF Institute of Aviation Medicine Report in preparation.
19. AGARD Aircraft Instrumentation and Cockpit Lighting by Red or White Light. (1957) AGARD Conference Proceedings 26.
20. Barratt, F.C., Doidge, P.F. & Honick, K.R. Simplified 1:250,000 Topographical Maps for Radar/Map Matching (1975) Royal Aircraft Establishment Report No. 75025.

DISCUSSION

M.Chevaleraud, CPEMPN, 5 bis, avenue de la Port de Sèvres, 75015 Paris: Could the author please state the results of the survey on the choice of lighting, with particular reference to the age of the pilots and the flight phase? May I quote our own results?

Author's reply: It was in fact a flight phase which was specific to low altitude flying with target identification. This is one of the most critical phases in operational flying and we obtained the views of pilots of transport helicopters and fast jets.

With regard to the age of the pilots, you will find all details in the text to be published. I can tell you now that the average age of the pilots was 30, with very slight variations above and below this figure.

M.Chevaleraud: I disagree slightly with your views at the end of your paper on lighting. Following a statistical survey covering civil and military pilots, we noticed a significant difference of opinion between pilots under 30 and those over 30. Among those over 30, it was observed that the older the pilots, the more they favoured white lighting. Furthermore and still arising out of the same questionnaire, it was noted that for take-off and landing they reduce the intensity of the white lighting and prefer the red, whilst for cruise conditions they again prefer white lighting.

M.Chevaleraud, CPEMPN, 5 bis, avenue de la Porte de Sèvres, 75015 Paris: Les résultats de l'enquête sur le choix de l'éclairage pourraient-ils être précisés par l'Auteur en tenant compte en particulier de l'âge et de la phase de vol? Puis-je apporter nos propres résultats?

Réponse de l'auteur: Il s'agissait effectivement d'une phase de vol spécifique à basse altitude avec identification d'un but. C'est en effet une des phases les plus critiques de la navigation aérienne opérationnelle, et nous avons recueilli l'avis de pilotes d'hélicoptères de transport et de jets rapides.

En ce qui concerne l'âge des pilotes, vous trouverez des données précises dans le texte qui sera publié. Je puis tout de suite vous dire qu'il s'agissait de pilotes ayant en moyenne 30 ans, avec des variations très légères en dessus ou en dessous de cet âge.

M.Chevaleraud: Je suis en léger désaccord avec vous sur la fin de votre communication concernant l'éclairage. Après une étude statistique portant sur des pilotes civils et militaires, nous avons constaté une différence significative entre l'opinion des pilotes âgés de moins ou de plus de 30 ans. Dans la catégorie des pilotes âgés de plus de 30 ans, on constate qu'plus les sujets vieillissent, plus ils recherchent un éclairage blanc. D'autre part, toujours à partir du même questionnaire on remarque que pour un décollage et pour un atterrissage, ils diminuent l'intensité de l'éclairage blanc et préfèrent le rouge, tandis qu'en vol de croisière c'est à nouveau le blanc qui a leur préférence.

MATRIX ELEMENT DISPLAY DEVICES AND THEIR APPLICATION TO AIRBORNE WEAPON SYSTEMS

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SUMMARY

A study was performed to determine the impact of two important matrix display design variables on tactical target recognition performance. Element density (i.e., the number of individual display resolution elements per degree as viewed by the observer) and the percent active area on the display surface were experimentally manipulated by adjusting the viewing distance from a rear projection screen over which a grid mask was placed. The targets were presented to subjects using zoom imagery at a simulated slant range which initially precluded recognition. As the target size increased, subjects were asked to press a remote projector control button when they were "virtually certain" of the correct response. The results indicate little effect of percent active area (i.e., down to 55 percent) on target recognition performance for element angular subtense values between 0.75 and 3.0 minutes of arc (corresponding to element densities of from approximately 165 to 40 elements per inch at a 28 inch viewing distance). The effects of element density, however, were large and conformed to expectations derived from the limiting resolution of the visual system. Geometric mathematical derivations are provided for the relationships between element density, viewing distance, target size, sensor field of view, total number of display elements and slant range at time of target recognition.

INTRODUCTION

Liquid crystal display (LCD) and light emitting diode (LED) display media offer several significant advantages over conventional Cathode-Ray Tubes (CRTs) for display of information in the airborne environment. The most important of these are related to electric power consumption and form factor (size). In addition, the operation of the LCD is such that in high ambient luminance conditions display brightness increases without causing a loss of contrast. An excellent discussion of the physical properties and characteristics of LCD's may be found in Lechner, et al. ⁽¹⁾ as well as in the most recent review by Goodman ⁽²⁾.

To insure that LCD devices are applied most effectively as candidate replacements for CRTs, several human factors issues need to be experimentally evaluated. The density of emitters in the matrix array and the percent active area on the display surface have been identified as areas of greatest concern. However, specific levels of percent active area and element density can be achieved, beyond which no additional improvement in operator performance could be expected. That is, if the number of resolution elements across the target exceeds the resolution capability of the human visual system, the operator, not the display, becomes the limiting factor in the visual task. If the number of elements across the target is less than the resolution capability of the visual system, then the display becomes the limiting factor. Figure 1 depicts these relationships for an arbitrary target recognition task.

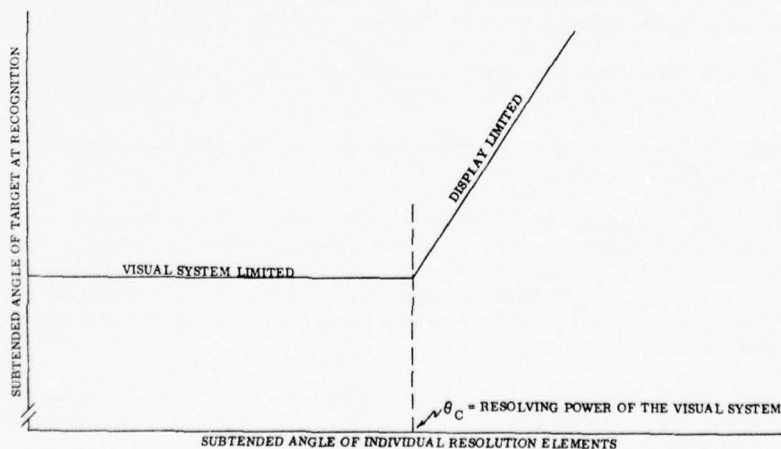


Figure 1. Subtended Angle of Target for a Given Probability of Recognition as it Theoretically Would be Influenced by Subtended Angle of Individual Resolution Elements in the Display.

METHOD

Subjects. Twenty-five college students whose ages ranged from 18 to 25 years served as subjects in this study. Each subject was reimbursed \$3.00 per hour for his participation and was prescreened to assure either unaided or corrected visual acuity of 20/20. Five males were used in the Pilot Study, while 17 males and 3 females were used in the Main Study.

Apparatus. A schematic diagram of the LCD simulator is shown in Figure 2. A 16mm movie projector was used to project stimulus imagery onto the rear surface of a hinged 1/8 in. x 8 in. x 8 in. glass rear projection screen. The hinge allowed photographically produced grid masks to be introduced between the projection screen and the clear glass front plate. The photographic grids provided a means of simulating the percent active area characteristics of a matrix display structure. The levels of percent active area simulated were 55, 69, 81 and 100 (i.e., no mask) percent.

The subject sat in front of the rear-projection device with his line of sight in the middle of and perpendicular to the viewing surface. A remote control switch was provided for subject control of the projector.

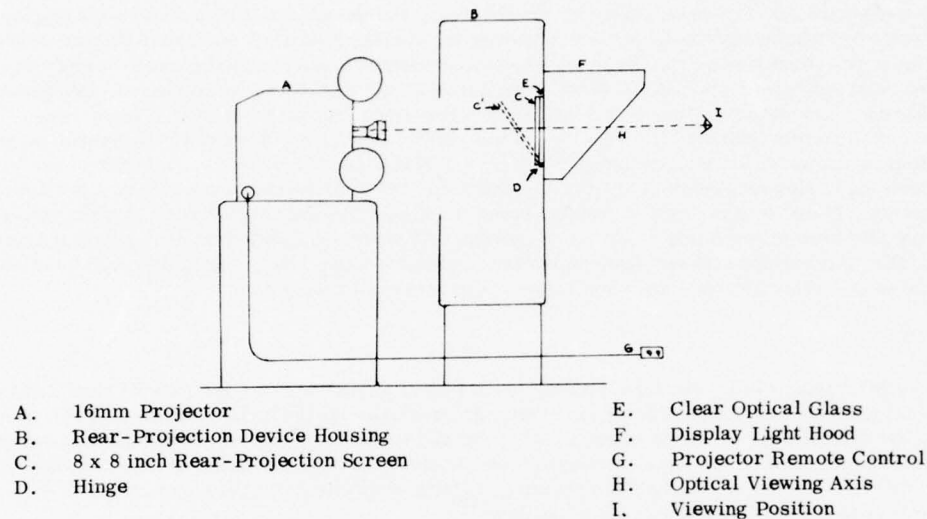


Figure 2. Schematic Diagram of Liquid-Crystal Dot-Matrix Simulator (Side View)

Stimulus Material. The 16mm movie film strips used were composed of continuous zoom sequences of still photographs of target vehicle models. There were five target models used: a tank, mobile gun, half-track, uncovered truck, and covered truck. To produce the movies, each target was mounted on a rectangular pseudo-random background floor tile. A still photograph was taken of each target positioned in each of four orientations. The longitudinal axis of the target was always aligned on the tile diagonal. This resulted in a total of 20 still photographs (five targets in each of four orientations). Each photograph was mounted on a homogeneous, gray background. At the onset of the 16mm filming of each target photograph, the camera was started at minimum lens magnification. The lens was zoomed during filming to maximum magnification. Minimum to maximum zoom took approximately 20 seconds, and the magnification ratio was 10:1. Development of the film was at a gamma of $1.0 \pm 1\%$. Only one set of the 20 zoom sequences was filmed, and reproductions of this original set were made for splicing.

Twelve film strips with random orders of the 20 target presentations were made by cutting, reordering, and splicing back together the 20 target zoom sequences to produce 12 copies for use in the experiment.

The viewing arrangement used resulted in unmasked display brightness levels of approximately 500 FtL at the center of the screen and 350 FtL at the edges.

Procedures and Design. Two studies were performed. The first of these, referred to as the pilot study, was designed to provide information regarding the extent of subject training required, the effect of subject instructions on target recognition accuracy, and identification of the appropriate range of element density values to be used in the larger main study effort. After these initial issues were resolved, the main study was carried on with strict control over these variables and was designed specifically to address the effects of element density and percent active area on target recognition performance.

Pilot study subjects were presented zoom imagery in the unmasked condition. The initial simulated slant range (target size) precluded recognition. As the target size increased, subjects were asked to press the remote projector control button as soon as they were able to recognize the target.

Three film strips were used for subject training. Subjects were prebriefed on the nature of the targets to be viewed using still photographs of the targets together with the actual target models. The film strips were repeated

until the subject showed less than 10 percent increase in mean performance for three successive presentations. This point was accepted as asymptotic for the subject and he was then considered ready to enter the second phase of the pilot study.

The purpose of the second phase of the pilot study was to determine the subject instructions which would yield a probability of correct target recognition greater than .95. The intent of this was to assure that the design criteria developed from the data would reflect relatively conservative estimates of display parameter requirements. Each subject was exposed to two series of target presentations. This two-series presentation was given twice to each subject. During one presentation, the subject was required to identify the target "as soon as he possibly could". On the other presentation, the subject was instructed to identify the target only "when he was virtually certain of his identification".

The minimum viewing distance of the seated subject was set at 28.7 inches. This was established by adjusting the throw distance of the projector to the screen so as to attain zero percent recognition by all subjects, prior to zooming the imagery.

In the final phase of the pilot study, subjects viewed selected film strips under masked conditions. The three percent active area grids (i.e., 55%, 69%, and 81%) were used. No grid-film strip sequence combination was repeated with any subject; nor did any subject view the same film strip sequence through more than one grid.

With each grid, the subject was positioned at a number of predetermined distances from the screen, shown a different film strip, and asked to repeat the recognition task. The angular subtense of individual elements was computed from the measured viewing distance. These values were 3.0, 2.0, 1.5, 1.0, 0.75, and 0.5 minutes of arc, and corresponded to viewing distances of 28.7, 43.1, 57.3, 86.2, 114.6, and 172.4 inches, respectively.

In the main study, a counterbalanced order of target conditions was established and each subject was randomly assigned to one of these orders, with an equal number of subjects for each order used.

Each subject was trained to the same asymptotic criterion as for the pilot study. Upon completion of the training trials, each subject was exposed to a total of $3 \times 3 \times 5 \times 4$ (i.e., grids \times element subtense \times targets \times target orientations), 180 trials under masked conditions of presentation, and to $3 \times 5 \times 4$ (i.e., element subtense \times targets \times target orientations), 60 trials under unmasked conditions.

For each grid, each subject was tested at the three viewing distances evolved from the pilot study to represent three levels of element angular subtense (i.e., 3.0, 1.5, and 0.75 minutes of arc).

The dependent variable in the main experiment was the subtended angle of the target at time of recognition. The data were analyzed within the framework of a 3×4 repeated measures analysis of variance design.

RESULTS AND DISCUSSION

Subjects in both the pilot and main study efforts required approximately ten training trials (or 200 stimulus presentations) to attain the criterion of three successive trials with less than ten percent improvement in mean performance.

The instructions to pilot study subjects to respond "as soon as possible" versus "when virtually certain" resulted in probability of correct recognition levels of approximately .80 and .96, respectively. Therefore, all main study subjects were instructed to respond "when they were virtually certain" of correctly recognizing the target. This produced a .96 probability of correct recognition for main study subjects as well.

The effects of angular subtense per element on the subtended angle of targets at time of recognition are shown for both the pilot study and main study data in Figure 3. Due to the small number of subjects in the pilot study, no statistical analysis was performed on those data.

An analysis of variance on the main study data, however, revealed that the effect of element angular subtense was highly statistically significant ($F = 27.5$, $p < .001$). These data are also plotted as a function of percent active area in Figure 4. As is obvious in Figure 4, percent active area (i.e., down to 55%) did not have a statistically reliable effect on the subtended angle across targets at time of recognition.

The theoretical relationship expressed in Figure 1 between the subtended angle across individual resolution elements and the subtended angle across targets at time of recognition is represented (for the pilot study data) by the dotted line in Figure 3. The "break" point between the visual system limited case and the display limited case appears to be at approximately 1.3 minutes of arc per element. This corresponds to just under 14 minutes of arc across the target at recognition time for the pilot study data and just over that value for the main study data. The discrepancies in ordinate values for the two sets of data are attributable to the slight differences in response criteria employed by the two sets of subjects. That is, as previously mentioned, the pilot study subjects had originally performed under two different instructional sets. That early experience apparently produced a slightly different response bias relative to main study subjects, even though all the data in Figures 3 were collected under the identical instructional set.

The data in Figure 3 were collapsed across target types and percent active area (i.e., grids). Shown in Figure 5 is a breakdown of main study data for each target type and at one representative grid condition (i.e., 81%). The starred positions represent the mean values across targets for the 81% grid condition. The standard deviation values

are identified by the dashed lines.

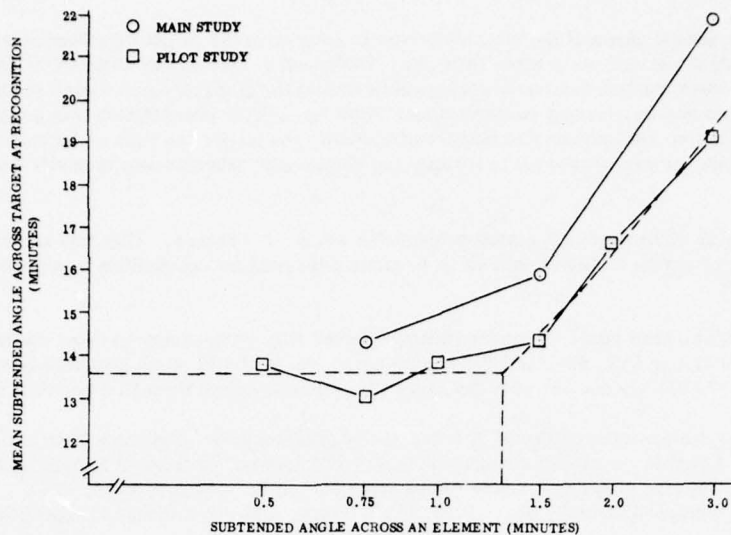


Figure 3. Comparison of Target Recognition Data - Actual vs. Theoretical and Pilot Study vs. Main Study

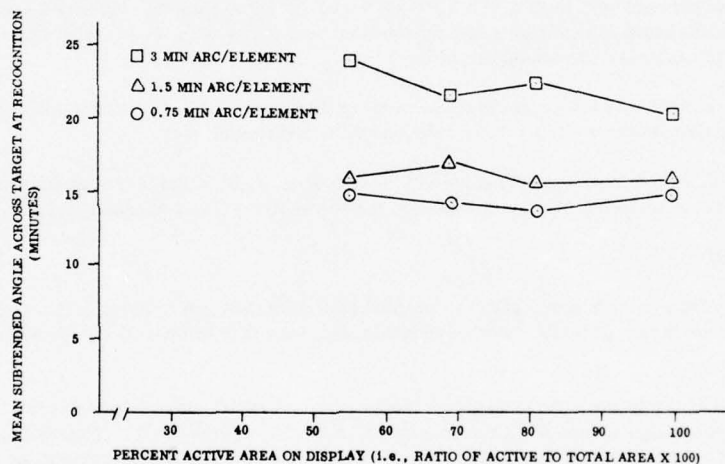


Figure 4. Effect of Grid Condition at Three Element Angular Subtense Values - Main Study

As is usual in studies of this sort, reliable differences were found between the various targets used, the tank and mobile gun being relatively easier to recognize (perhaps due to the gun barrels) than were the trucks or half track. Figure 5 also illustrates the fact that a major portion of the variance in the data was attributable to target type.

Figure 6 depicts the viewing geometry for a single element on a matrix display surface. The relations shown in this figure dictate that the tangent of the angle $\Theta/2$ ($1/2$ the subtended angle of a single display element) is equal to the opposite side ($d/2$) divided by the adjacent side (viewing distance, D). In equation form, then

$$\tan (\Theta/2) = \frac{(d/2)}{D} = \frac{d}{2D} \quad (1)$$

solving for d

$$d = 2D \tan (\Theta/2) \quad (2)$$

The lineal element density of the display is simply the reciprocal of the length of one side of a single element and is thus expressed as

$$\text{Element density} = e = \frac{1}{d} = \frac{1}{2D \tan (\Theta/2)} \quad (3)$$

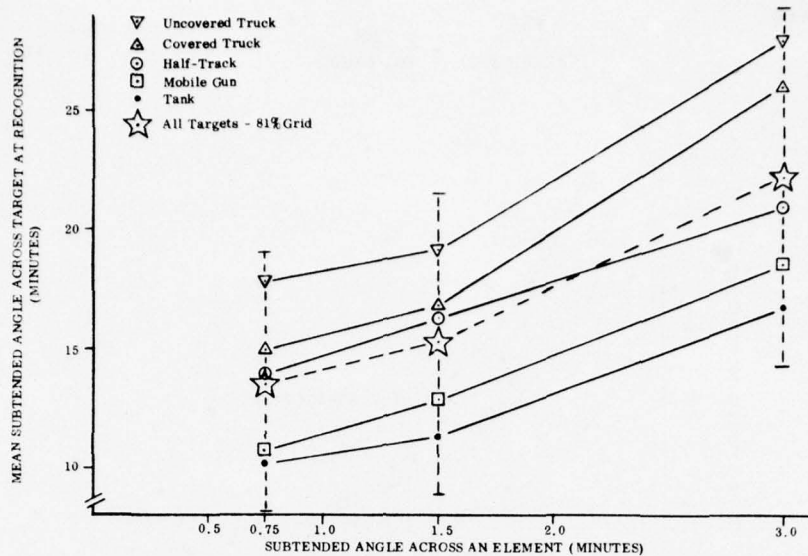


Figure 5. Effect of Element Angular Subtense on Target Angular Subtense at Time of Recognition for One Representative Grid Condition (81%) - Main Study

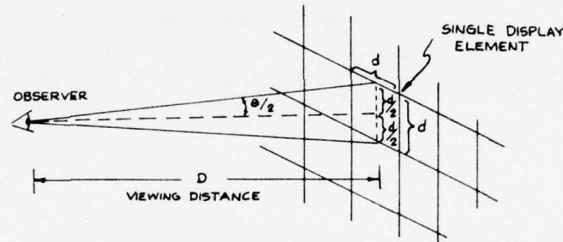


Figure 6. Geometry Relating Viewing Distance (D), Element Angular Subtense (Θ) and Element size (d)

The graphs in Figure 7 show a plot of this equation for three assumed values of eye resolution capability (Θ_c). The impact of the empirically determined value of Θ_c (i.e., 1.3 minutes of arc) is illustrated in Figure 7 for a viewing distance of 28 inches. As shown with the dashed line, a "break" point of 1.3 minutes of arc corresponds to a requirement of just under 100 elements per inch at a 28 inch viewing distance. Element density requirements at other viewing distances may be similarly derived.

Similarly, Figure 8 shows the geometry relating the field of view of a sensor (ϕ) to angular size of the target as viewed by the sensor (S), the perpendicular field distance (h), and slant range to the target (R).

From the relations shown in Figure 8

$$\tan(\phi/2) = \frac{(h/2)}{R} \quad (4)$$

solving for R:

$$R = \frac{h}{2 \tan(\phi/2)} \quad (5)$$

Assuming the target covers some fractional portion of the scene viewed by the sensor, the fraction (S/h) is equal to the fractional portion of the display across which the target appears. Similarly, for recognition to occur the target must appear across n_c elements of a square display having N elements along one dimension. The following relationship therefore holds as a recognition criterion:

$$S/h = n_c/N \quad (6)$$

solving for h:

$$h = \frac{NS}{n_c} \quad (7)$$

Substituting into equation (5)

$$R = \frac{NS/n_c}{2 \tan (\Phi/2)} = \frac{NS}{2n_c (\Phi/2)} \quad (8)$$

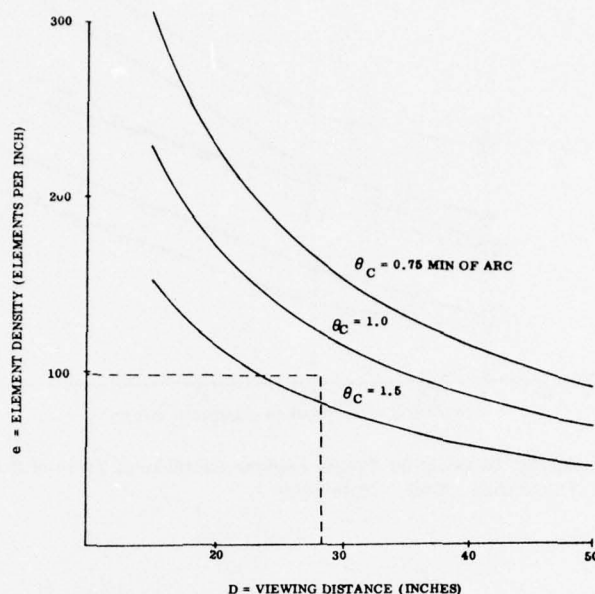


Figure 7. Required Element Density vs. Viewing Distance Across Alternative Levels of Eye Resolution or "Break" Points Between the Visual System Limited Case and the Display System Limited Case

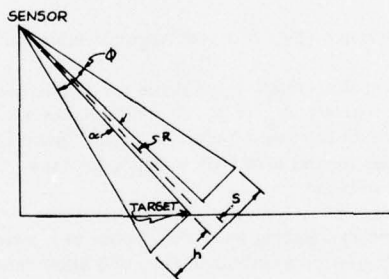


Figure 8. Sensor Geometry

The only variable in equation (8) which must be experimentally determined is n_c . The value of n_c depends on the viewing distance from the display, the lineal element density and the specific target recognition task under consideration. The value of n_c for the target set used in this study can be obtained from the data in Figure 3.

From these data it appears that approximately 14 minutes of arc across the target is required for target recognition. The maximum element size at which the 14 minutes of arc asymptote is obtained is approximately 1.3 minutes of arc per element. For a square element of 1.3 minutes of arc on a side, the diagonal angular size is 1.84 minutes of arc. Since the target appeared along a diagonal of the display, it is necessary to calculate n_c using the diagonal measure of the display element.

Thus,

$$n_c = \frac{14 \text{ minutes of arc required for recognition}}{1.84 \text{ minutes of arc per element}} \\ \approx 7.6 \text{ elements}$$

The relationships expressed in equation (8) may be plotted for any particular square display dimension and target size. Figures 9a and 9b reflect these relations for an 8-foot and 30-foot target, respectively. Note that differences in target size produce only a change in ordinate scale values.

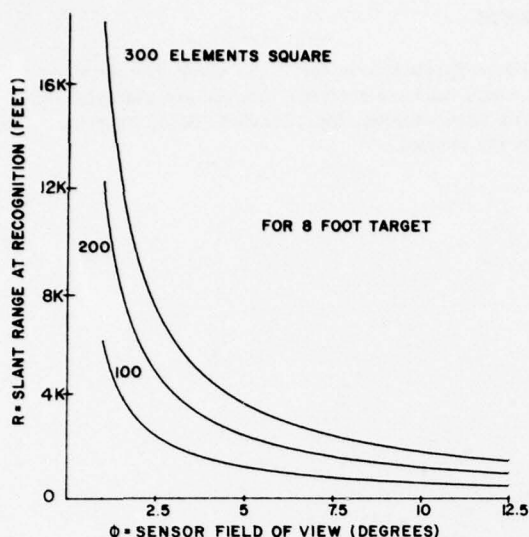


Figure 9a. Slant Range at Recognition for an 8-Foot Target vs. Sensor Field of View for Three Square Matrix Display Sizes

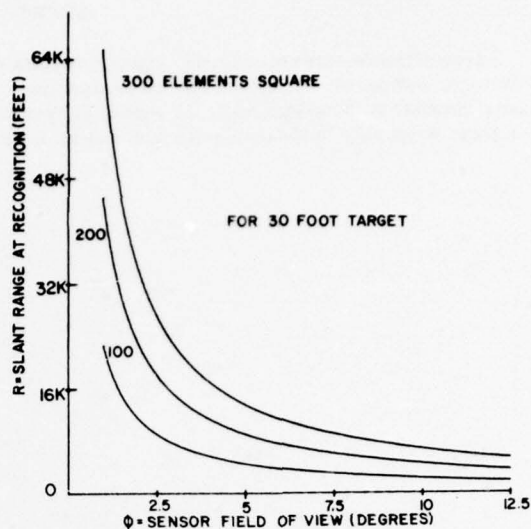


Figure 9b. Slant Range at Recognition for a 30-Foot Target vs. Sensor Field of View for Three Square Matrix Display Sizes

CONCLUSIONS

The curve relating element angular subtense to target recognition performance corresponds to that predicted. The "break" point in the curve appears to occur at approximately 1.3 minutes of arc. For a seated operator at a 28 inch viewing distance, this yields a desired element density of just under 100 elements per inch. LCD's currently being produced with 100 elements/inch will most likely provide adequate resolution for operational applications requiring a direct panel display and a 28 inch or greater viewing distance.

Above 55 percent active area, there appears to be no effect on visual performance of this variable.

Not unexpectedly, training in the visual task and instructional set have a major impact on performance results.

Related CRT research to determine the number of TV scan lines required for recognition of either static or dynamic tactical target imagery has indicated that 25 to 40 scan lines must cover the target to obtain operator performance levels comparable to the 96 percent correct responses in the present study (see Scott and Hollanda⁽³⁾; Bruns⁽⁴⁾; Lacey⁽⁵⁾). In addition, evidence from the referenced studies indicate that targets must also subtend at least 25 to 40 minutes of arc. The angular subtense values at target recognition obtained in the present study (i.e., approximately 11 to 28 minutes of arc) certainly compare favorably. However, it must be pointed out that the small number of targets (i.e., five) and the simulation technique (e.g., incorporating film) used in the present study make a strict comparison of CRT and simulated LCD data tenuous.

REFERENCES

1. Lechner, B. J., Marlow, F. J., Nester, E. O., and Tufts, J., Liquid Crystal Matrix Displays, Proceedings of the IEEE, Vol. 59, No. 11, November 1971.
2. Goodman, L. A., The Relative Merits of LED's and LCD's. Proceedings of the Society for Information Display (SID), Volume 16, Number 1, 1st Quarter 1975.
3. Scott, F. and Hollanda, P. A., The Informative Value of Sampled Images as a Function of the Number of Scan Lines Per Scene Object. *Science and Engineering*, Volume 14, Number 1. January-February, 1970, pp. 21-27.
4. Bruns, R. A., Dynamic Target Identification on Television as a Function of Display Size, Viewing Distance, and Target Motion Rate, Naval Missile Center, Pt. Mugu, California. TP-70-60, November 1970.
5. Lacey, L. A., Effect of Raster Scan Lines, Image Subtense, and Target Orientation on Aircraft Identification on Television, Aircraft Systems Dept., Naval Weapons Center, China Lake, California. May 1975. (NWC TP 5025).

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A THEORETICAL FRAMEWORK TO STUDY THE EFFECT OF COCKPIT INFORMATION BY

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SUMMARY

This paper deals with a theoretical framework describing human operator's participation in manned vehicle systems. Herewith, the human operator is described in terms commensurate with those used for other system elements, which is desirable because of the complex interaction between human functioning and his task environment (e.g., cockpit information). The result is an integrated model of the man-machine situation serving as a diagnostic tool (for existing systems) and allowing the extrapolation to new situations.

The theoretical framework deals with manned vehicle systems involving the human operator performing continuous control and/or decision making tasks. In the paper it will be illustrated how the effect of cockpit information (e.g., type, quality and interference of displayed information, both visual and auditory) on human functioning and mission success can be operationalized and straightforwardly investigated.

1 INTRODUCTION

In spite of an increasing awareness of the necessity to emphasize the human operator's participation in manned vehicle systems, there are still very few satisfactory tools to describe the human's role in these systems. One promising approach concerns the use of mathematical models of human behavior.

Because of the complex interaction between human functioning and his task environment (for cockpit information problems the subject of investigation *per se*), it is desirable to describe the human operator in terms commensurate with those used for other system elements. The result is an integrated framework of the man-machine situation so as to fulfil two basic functions.

The first function is to serve as a diagnostic tool. This concerns the analysis of experimental results and the "explanation" of system characteristics. Especially model parameters related to the human operator are often more sensitive measures than overall system performance.

The second function is the extrapolation to new situations. Early in the design stage competing systems must be evaluated. Therefore, the complex interaction among system components (task environmental and human related) and objectives must be investigated.

Several requirements which the theoretical framework describing the man-machine system has to meet, can be derived from the foregoing.

- . The model structure must allow to treat realistic, complex task situations. This implies a multivariable approach.
- . In order to be predictive, the model structure may not depend on specific task characteristics. This is one of the main drawbacks of the conventional servo system models (Ref. 1), requiring assumptions about how the human utilizes the various inputs and how he executes the various responses (loop structures).
- . Dealing with time-varying tasks, the model structure must be formulated in the time domain. This allows a detailed description of the relevant task characteristics, as opposed to "frequency domain" models, which are strictly valid only for stationary task situations. For these models any system- or human performance measure is an overall descriptor (time average) of the manned vehicle system.

The most general theoretic framework meeting the afore-mentioned requirements, is provided by the state space optimization-, estimation- and decision theory. It consists of several submodels, corresponding with pertinent human operator characteristics (functions). One submodel describes the manner in which the human will process the information available to him, to generate an estimate of the system state. This can be associated with an internal representation of the task environment (internal model) and allows a systematic investigation of a variety of cockpit informational aspects. This submodel is in the following denoted by the perceptual model. Combined with a submodel for human control response this results in a model for human control behavior, known as the optimal control model (Ref. 2). The perceptual model is also part of a model for human decision making (Refs. 3 and 4). Furthermore, interference between several subtasks (control and/or decision making) is accounted for by the task interference model presented in reference 5. The result is an integrated model of three important human operator functions: monitoring, controlling and decision making.

In the next section the afore-mentioned models will be reviewed. The various human operator characteristics will be emphasized in accordance with their relevance for the subject of this paper. It will be indicated to which extent the various aspects of the framework are validated.

In section 3, the models will be demonstrated to provide a flexible and powerful tool for synthesizing and analyzing systems involving the human operator performing continuous control and/or monitoring tasks. It will be illustrated how the effect of various cockpit informational aspects (e.g., type, quality and interference of displayed information, both visual and auditory) on human functioning (performance and workload) can be operationalized and straightforwardly investigated.

2 THEORETICAL FRAMEWORK

2.1 Optimal control model

Human control behavior is described by means of the optimal control model (OCM). The model which is developed by Kleinman and Baron (Ref. 2) is based on optimization and estimation theory and can be used to describe multivariable linear control situations. As the model is formulated in the time-domain, time varying characteristics can be dealt with.

The model is based on the assumption that the well-motivated, well-trained human operator behaves in a near optimal manner subject to his inherent limitations and constraints and the extent to which he understands the objectives of the task. In the next paragraph those limitations are discussed which are incorporated in the human operator model. It can be considered as a submodel of the OCM which involves also a description of the task (environment) and the task objectives.

2.1.1 Human operator model

The following psychophysiological limitations of the human operator are dealt with in the model

1. The various internal time delays associated with perceptual (visual, aural, vestibular, etc.), central processing and neuromotor pathways are represented by a lumped equivalent perceptual time delay, τ .
2. The various sources of human randomness (unpredictable in other than a statistical sense) are presented by errors in observing system outputs and executing control inputs by including observation noise and motor noise in the model.

The foregoing can mathematically be represented in an "equivalent" perceptual model and an "equivalent" response model.

2.1.1.1 Perceptual model

The perceptual model indicates that the "perceived" variables, y_p , are noisy, delayed replicas of the "displayed" variables y , according to

$$y_p(t) = y(t-\tau) + v_y(t-\tau) \quad (1)$$

where τ is the aforementioned time delay, and v_y is a vector of independent, white, Gaussian observation noises.

The observation noise associated with a given display variable is statistically defined by its autocovariance which appears to vary proportionally with the mean-squared signal level and may be represented as

$$E \left\{ v_{y_i}(t) v_{y_i}(\sigma) \right\} = v_{y_i}(t) \delta(t-\sigma) \quad (2)$$

and

$$v_{y_i}(t) = \tau P_{y_i} E \left\{ y_i^2(t) \right\} \quad (3)$$

where P_{y_i} is the "noise/signal" ratio and has units of normalized power (positive frequencies) per rad/sec.

In case of non-idealized displays a more general expression for the observation noise covariance includes threshold effects (to be associated with display phenomena or "indifference" thresholds) and lack of reference indicators (Ref. 2).

Optimal estimation (Kalman-Bucy filter) and prediction (least mean-square prediction) of the system state, $x(t)$, given $y_p(t)$, results in the human's internal representation, $\hat{x}(t)$, representing a model for human information processing.

2.1.1.2 Response model

Human response selection is assumed to be generated by a control-command process which is represented by a set of optimal gains, L , operating on the estimated state, $\hat{x}(t)$, according to

$$u_c(t) = -L \hat{x}(t) \quad (4)$$

The human response execution model indicates how the "commanded" control, u_c , results in the actual control input, u , according to

$$T_N \dot{u} + u = u_c + v_u \quad (5)$$

where T_N is the "neuro-motor" lag matrix, which can be identified with neuro-motor bandwidth limitations and/or pilot reluctance to make rapid control movements; v_u is an "equivalent" motor noise vector representing human's imperfect knowledge of generating control inputs with autocovariance

$$E \left\{ v_{u_i}(t) v_{u_i}(\sigma) \right\} = v_{u_i}(t) \delta(t-\sigma) \quad (6)$$

2.1.2 System and task description

The human operator's task is to control, in some way, a dynamic system. The linear(ized) system description comprises the controlled element, any dynamics associated with measurement, control and display systems as well as the disturbance environment. The equations for the dynamics are represented by

$$\dot{x}(t) = A x(t) + B u(t) + E w(t) \quad (7)$$

where $x(t)$ is the vector of the system states, $u(t)$ is the vector of human control inputs and $w(t)$ is the vector of linear independent, Gaussian, white noises with autocovariance $E \{ w(t) w(\sigma) \} = W \delta(t-\sigma)$.

The display variables, y , are assumed to be linear combinations of the state and control variables

$$y(t) = C x(t) + D u(t) \quad (8)$$

The control task is specified in terms of a performance criterion that the human is to optimize. This criterion is incorporated in a cost functional conditioned on the observations, y_p , which in the steady-state is minimal for the optimal control input

$$J(u) = E \{ y'(t) Q y(t) + u'(t) R u(t) + \dot{u}'(t) G \dot{u}(t) \} \quad (9)$$

where Q , R and G are the cost functional weightings which can depend on objective or subjective factors. The weighting on control rate implies the aforementioned "neuromotor" lag matrix (if $G = 0$, $T_N = 0$).

For the mathematical formulation of the aforementioned optimization problem the reader is referred to reference 2.

A variety of measures of system performance and human operator-related measures can be obtained. These will be discussed in the next paragraph.

2.1.3 System performance and human control effort

For stationary processes system performance can be formulated in variance and probability computations. Human operator performance is reflected by variances of control inputs. Also frequency domain measures can be obtained such as describing functions, remnant and power spectra (Ref. 2).

In case of deterministic inputs and time-varying characteristics of the task environment, such as disturbance variations, windshears, variations in displayed information, vehicle dynamics and task instructions (different mission segments, approaching the target, etc.), the previously discussed time-average measures are not applicable. Now, performance is conveniently described by means of covariance propagation methods. Statistically, this implies ensemble-averaging.

Also the aspect of human controller's effort is indispensable for a complete description and prediction of human operator behavior and its impact on mission success. Because of the adaptive capabilities of the human it is often the most sensitive to task characteristics under consideration. A control effort model is developed in terms of the afore-mentioned theoretical framework. The model involves both voluntary attention (Ref. 5) and involuntary attention (Ref. 6) of the human operator. The latter aspect can be related to the level of arousal and is largely dictated by the properties of the displayed information (Ref. 7).

The optimal control model has been validated against experimental data for a variety of both stationary and non-stationary control tasks (see e.g. Refs. 2-6). Many of its applications have been with respect to display evaluation. Some examples of these will be contained in section 3.

2.2 Human monitoring and decision making model

2.2.1 General

Describing human operator's participation in manned vehicle systems involves often other functions than the control function. Human monitoring and decision making can be crucial functions to fulfil, especially in view of increasing complexity and automation of aerospace vehicles.

Human decision making behavior is described by the afore-mentioned perceptual model, however now in a cascade combination with the subjective expected utility model (Refs. 8 and 9). The perceptual model generates an estimate, $\hat{x}(t)$, of the system state. In addition, the covariance of the error in that estimate, $\Sigma(t)$, is available. The pair $(\hat{x}(t), \Sigma(t))$ constitutes a sufficient statistic for testing hypotheses about $x(t)$ based on the data, $y_p(s)$, $s \leq t$.

It is assumed that the human's decision strategy is reflected by the following stages

- . formulate (N) possible hypotheses, h_i
- . assess probabilities of all hypotheses, based on relevant information z , $P(h_i/z)$
- . determine (M) possible decisions, D_i
- . assign utilities to each hypothesis/decision combination, U_{ij}
- . determine the maximum utility-decision D^* according to $D_i^* = \arg \max_j U_{ij}$ for $E = E_{\max}$, where

$$E \left\{ U/D_i \right\} = \sum_{j=1}^N U_{ij} P(h_j/z) \quad (10)$$

Many decision making situations involve binary decisions. In that case

$$D = D_1 \text{ if } \frac{P(h_1/z)}{P(h_0/z)} > \frac{U_{00}-U_{10}}{U_{11}-U_{01}} \equiv \frac{U_0}{U_1} \quad (11)$$

$$D = D_0 \text{ otherwise}$$

Once the utilities have been specified, the model can be used to compute the monitoring error probabilities (wrongly deciding D_0 and D_1).

The model described above is validated for single variable tasks (Ref. 3) as well as for multivariable hypotheses (up to three display variables) situations (Ref. 4).

For multivariable control and/or decision making tasks human attention has to be divided among the various sources of information (e.g., display indicators). This attention sharing is described by the task interference model of reference 5 which is briefly discussed in the next chapter.

2.3 Task interference model

Task interference is modelled in terms of the following relationship between the fraction of attention, f_i , paid to subtask (source of information) i , and the corresponding human's internal noise/signal ratio, P_i

$$P_i = P_{0i}/f_i \quad (12)$$

where P_{0i} is the ratio corresponding to single-task performance ("full attention"). Furthermore, it is assumed that the amount of information processing capacity is determined by the demand of the subtasks and not by the amount of subtasks to perform. In formula

$$\sum_{i=1}^M f_i = 1 \quad (13)$$

This model developed by Levison et al (Ref. 5) has been validated for some multivariable control situations (Ref. 5) and dual decision making and control tasks (Ref. 3).

Reference 4 deals with experimental results of multivariable decision tasks and combined decision tasks and (both visually and auditory presented) control tasks. Also in this reference a multivariable workload model is presented based on the fractional attention concept.

3 ILLUSTRATION

In this section it is illustrated how the model can be utilized to study the effect of cockpit information on human control- and monitor behavior. Specifically, some results will be discussed of an experimental program presented in reference 4, dealing with human decision making behavior for various task situations (in a fixed-base simulator).

The first task was monitoring an automatic approach of a DC-8. The pilot's task was to decide whether or not he was within the "landing window" (speed, glideslope and localizer within their region of acceptable deviations) utilizing a response button (Fig. 1). Based on a single-indicator "calibration" experiment and using the afore-mentioned decision making model and task interference model, decision errors were predicted for both two-(speed and glideslope), and three indicator tasks (indicated with M2 and M3, respectively). Table 1 contains a comparison of measured and predicted scores for each configuration. The excellent agreement between the scores reveals the predictive power of the models involved.

Next, the results will be discussed of two combined control- and decision tasks.

The first configuration concerned the longitudinal (flight director) control of a DC-8 approach and simultaneously monitoring the afore-mentioned three indicators, indicated with M3C. Matching the control scores the apparent fraction of attention dedicated to the control task was determined and using the task interference- and decision making model the monitor performance measures were predicted. The result is shown in table 2 revealing that especially the total decision error agrees surprisingly well with the measured error and that the models apparently provide a good description of human behavior in a relatively complex and realistic task situation.

The results of the second configuration are discussed here to illustrate the difference in interference between visual information and visual/aural information. The afore-mentioned monitor task (M3) was combined with an auditory tracking task. The same model procedure was followed as before. However, predicted monitor performance based on the full interference hypothesis ($\Sigma f = 1$) is worse than the actually measured performance as can be seen in table 2. Matching the measured monitor performance corresponds with less than full interference ($\Sigma f = 1.2$) between visual and auditory tasks. Herewith, it is illustrated that the models allow a quantitative description of interference between visual and auditory information.

Referring to the foregoing discussion and based on several display evaluation studies (e.g., Refs. 10-12) it is concluded that the theoretical framework provides an adequate description of many relevant

man-machine situations. It allows a meaningful investigation of various task characteristics, specifically, a variety of cockpit informational aspects.

4 REFERENCES

- 1 McRuer, D.T. and Mathematical Models of Human Pilot Behavior.
Krendel, E.S. AGARD-AG-188, January 1974.
- 2 Kleinman, D.L. and Manned Vehicle System Analysis by means of Modern Control Theory.
Baron, S. NASA CR-1753, June 1971.
- 3 Levison, W.H. and A Control Theory Model for Human Decision-Making.
Tanner, R.B. NASA CR-1953, December 1971.
- 4 Wewerinke, P.H. Human Control and Monitoring-Models and Experiments.
Paper presented at the Twelfth Annual Conference on Manual Control.
University of Illinois, Urbana, USA, May 1976.
NASA TMX (forthcoming).
- 5 Levison, W.H. et al Studies of Multivariable Manual Control Systems.
A Model for Task Interference.
NASA CR-1746, May 1971.
- 6 Wewerinke, P.H. Effort involved in Single- and Two-Axis Manual Control Systems.
NLR TR 75060 U, November 1974.
- 7 Kahneman, D. Attention and Effort.
Prentice-Hall Inc., 1973.
- 8 Edwards, W. et al "Emerging Technologies for Making Decisions", in New Directions in Psychology II.
Holt, Rinehart and Winston, New York, 1965.
- 9 Edwards, W. and Decision Making. Penguin Modern Psychology Readings.
Tversky, A. (editors) UPS 8, 1967.
- 10 Baron, S. and A Manual Control Theory Analysis of Vertical Situation Displays for STOL Aircraft.
Levison, W.H. BBN Report No. 2484, April 1973.
- 11 Baron, S. et al Application of Optimal Control Theory to the prediction of Human Performance in
a Complex Task.
AFFDL-TR-69-81, March 1970.
- 12 Kleinman, D.L. and Analytic Evaluation of Display Requirements for Approach to Landing.
Baron, S. NASA CR-1952, November 1971.

CONF.	PROBABILITY	P (H_0)	P (D_0)	P (H_1, D_0)	P (H_0, D_1)	P _e
M2	MEASURED	.56	.53	.050	.079	.129
	MODEL	.56	.52	.048	.082	.130
M3	MEASURED	.47	.44	.060	.088	.148
	MODEL	.47	.42	.053	.097	.150

Average of 4 subjects, 4 runs per subject

Table 1: Comparison of measured and predicted decision making scores for the monitoring tasks.

CONF.	PROBABILITY	P (H_0)	P (D_0)	P (H_1, D_0)	P (H_0, D_1)	P _e
M3C	MEASURED	.36	.32	.086	.115	.201
	MODEL	.36	.31	.072	.128	.201
M3A	MEASURED	.47	.43	.065	.096	.161
	MODEL	.47	.42	.067	.117	.183
	$\Sigma f = 1$					
	MODEL	.46	.42	.060	.101	.161
	$\Sigma f = 1.2$					

Average of 4 subjects, 4 runs per subject

Table 2: Comparison of measured and predicted decision making scores for the combined control- and monitoring tasks

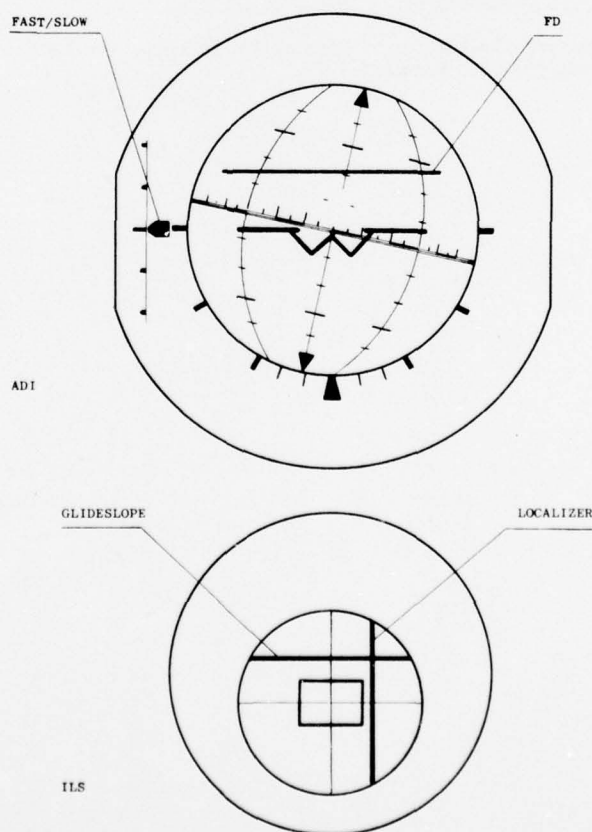


FIG. 1: DISPLAY FORMAT

DISCUSSION

I.D.Best, Hawker Siddeley Aviation Ltd, Richmond Road, Kingston upon Thames, England: You said that a pilot will react reasonably according to his training, and indeed the model correlations you showed were encouraging. On the question of critical phases of flight, however, do you intend to take account of pilot stress. It has been shown that under overload an operator's output undergoes a considerable hysteresis effect which inevitably degrades his performance.

Author's reply: I did not have time to speak about the different workload. The workload model includes the amount of attention necessary, and the stress is that of the pilot. This model does not take into account some aspects of the system and I did not directly include the stress in this outline. It is possible to obtain an information on the interface man-machine, notably by measurement of the cardiac rhythm.

I.D.Best: The cardiac rhythm increases before the stress, and not during the stress?

Author's reply: I agree.

CONCLUSIONS

by

Médecin Général Perdriel

Nous avons constaté que le nombre et la complexité des instruments et des cadrans disposés dans le cockpit tendent à augmenter constamment, ce qui risque de nuire à l'efficacité visuelle du pilote.

Aussi est-il devenu nécessaire de réduire cette multiplication dangereuse utilisant des procédés nouveaux permettant de faciliter l'information visuelle, notamment dans certaines conditions particulières du vol (basse altitude et grande vitesse par exemple).

Plusieurs de ces procédés ont été décrits dans cette session:

- amélioration des conditions d'éclairage de certains instruments.
- projection de cartes avec utilisation de couleurs bien choisies.
- essais de superposition de l'information cartographique aux informations radars.
- mise en oeuvre de différentes techniques permettant:
 - (a) de substituer l'information tridimensionnelle à celle portant sur deux dimensions.
 - (b) utilisation d'un horizon artificiel magnifiant la représentation classique.
 - (c) application de la stéréovision pour apprécier l'aspect du terrain lors du vol.
 - (d) amélioration de la visualisation des informations grâce à l'emploi de cristaux liquides.

Si la réalisation expérimentale s'est avérée dans plusieurs cas satisfaisante, il paraît nécessaire, avant d'adopter ces différents systèmes, de confirmer:

- leur efficacité opérationnelle,
- leur acceptation par les pilotes,
- et leur compatibilité en poids et en volume avec les performances de l'avion.

We have seen that cockpit instruments and dials are tending to become increasingly more numerous and complex, a fact which may be harmful to the pilot's visual efficiency.

It has therefore become necessary to reduce this dangerous multiplicity of instruments by introducing new methods aimed at facilitating visual information, particularly in certain special flight conditions (e.g. low altitude and high speed).

Several of these methods have been described during this Session:

- Improving the lighting conditions of certain instruments;
- Map projection using well chosen colours;
- Tests on superimposing cartographic information on radar data;
- Applying various techniques for:
 - (a) replacing two-dimensional data by three-dimensional data;
 - (b) using an artificial horizon to magnify the conventional data display;
 - (c) using stereovision to assess terrain characteristics during flight;
 - (d) using liquid crystals to improve data displays.

Although experimental development work has proved satisfactory in several cases, it would appear to be necessary before finally adopting these various systems, to confirm:

- that they are operationally efficient;
- that they are acceptable to pilots;
- that they are compatible from the weight and size point of view with the performance of the aircraft.

D-1

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